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Insights on Digital Flight

Ruth E. Stilwell

Aerospace Policy Solutions, LLC, Lauderdale-by-the-Sea, FL

William B. Cotton

Cotton Aviation Enterprises Inc. Lakeway, TX

Anna M. Dietrich

AMD Consulting, LLC, Petaluma, CA

John Maris

Advanced Aerospace Solutions, LLC, Carlisle, MA

Paul Vajda

Advanced Aerospace Solutions, LLC, Carlisle, MA

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1. INTRODUCTION

Aviation is at a transformative moment as significant as the development of Instrument Flight or the advent of Radar. The ability to fly without a pilot on board, relying on data from external sources, digital connectivity, and automation, creates an opportunity to revolutionize systems in the air and on the ground. Integrating these digital systems into aviation's human centric procedures has challenged existing paradigms as many efforts have sought to bend the new entrant model to fit the legacy system. This approach risks limiting the potential of a digital future for aviation. Digital Flight, a proposed new operating mode based on reference to digital information, informed the digitally enabled cooperative operations (DECO) research activity within NASA's Convergent Aeronautics Solutions project. This research included insights from a broadly diverse set of subject matter experts tasked with identifying the desirability, viability, and feasibility of operator-responsible separation based on digital information. Analytical Mechanics Associates supported this research activity, employing subject matter experts (SMEs) from four subcontracting entities, Aerospace Policy Solutions, LLC, Cotton Aviation Enterprises, Inc., AMD Consulting, LLC, and Advanced Aerospace Solutions, LLC (AdvAero). This report shares the insights of these experts and complements NASA technical memoranda published during the activity period.

Throughout the activity period, various terms have been used by different entities to discuss the concept of operator responsible aircraft separation including, Digital Flight, digital flight rules, automated flight rules, cooperative operations, cooperative separation, digital VFR (Visual Flight Rules), autonomous separation, and tailored flight rules. This research activity utilizes the terms digitally enabled cooperative operations and Digital Flight interchangeably to refer to operations where an aircraft operator is responsible for conflict management using digital tools to ensure safe separation between their aircraft and other aircraft and hazards.

The DECO activity uses the term "operating mode" to characterize the technical capabilities, conditions, and regulatory frameworks that serve as the basis for permitting flight in the National Airspace System (NAS). Currently, the operating modes routinely used in the NAS are Instrument Flight Rules (IFR) and Visual Flight Rules (VFR). However, the Federal Aviation Administration (FAA) authorizes flight under other operating modes specific to the operational needs of certain mission types, like parachute operations, small unmanned aircraft systems (sUAS), or ultralight aircraft. An operating mode specifies the accountable parties in conflict management and provides for self-executing approval. That is to say, if an operator meets the requirements of the operating mode's regulations (including required certifications), flight in the NAS is permitted. Operations outside the defined operating modes require independent authorizations or waivers for flight in the NAS to be allowed.

This report includes the evolution of thought and analysis of Digital Flight by the subject matter expert (SME) subcontractors in the DECO activity to support the efforts of future researchers.

Project Subject Matter Experts

Each SME is a recognized expert in their field and brings decades of experience that informs their perspective on Digital Flight as evidenced by their biographies below. Unlike projects that describe an aspirational future, the knowledge and experience of these experts allowed the DECO research activity to develop pathways to operationalize the future state where a digital operating mode is as routine as the visual and instrument operating modes.

CPT. WILLIAM "BILL" COTTON, COTTON AVIATION ENTERPRISES, INC.

Captain Cotton is known worldwide as the "Father of Free Flight", the Air Traffic Management (ATM) operating concept for the future that would simultaneously increase safety, capacity, and operating efficiency in the air traffic system. As the chief technical pilot at United Airlines, he directed all air traffic control and flight systems related efforts for the company, including the National Route Program, Collaborative Decision Making (CDM), and establishing routes across Russia and China. Cpt. Cotton managed numerous avionics projects from concept through development and implementation, and has been a key innovative participant in many industry activities to bring new aviation technologies to fruition, such as Traffic Alert and Collision Avoidance Systems (TCAS), Automatic Dependent Surveillance – Broadcast (ADS-B), DataComm, and Future Air Navigation System (FANS-1). Cpt. Cotton has a Bachelor of Science (BS) in Aeronautical and Astronautical Engineering from the University of Illinois and a Master of Science (SM) of Aeronautics and Astronautics from the Massachusetts Institute of Technology (MIT).

After retiring from United, Cpt. Cotton was President of Flight Safety Technologies, Inc. creating and managing the company's strategy for developing its air safety technologies. This included creation of the concepts of operation and the operational design of its safety systems including the patented Unicorn aircraft proximity and collision alerting system, and the Aircraft Wake Safety Management system for increasing airport capacity.

Cpt. Cotton is most recently an aviation consultant working with NASA in their efforts to improve the safety of operations and increase the capacity of the airspace, including Digital Flight (DF) or Digitally Enabled Cooperative Operations (DECO). Previously, he has worked with NASA and FAA to develop Traffic Aware Strategic Aircrew Requests (TASAR), Airborne Trajectory Management (ABTM), Autonomous Flight Rules (AFR), Trajectory Based Operations (TBO), Trajectory Synchronization among FAA ground automation systems, ATM Function Allocation and the investigation of all self-separation concepts for NASA under their Airspace Systems Program. He has also worked with leading researchers at NASA Langley and Ames research centers on proposals for Unmanned Aircraft Systems (UAS) ATM to accommodate Advanced Air Mobility (AAM). He is an active pilot, flight instructor, and aerospace engineer.

ANNA DIETRICH, AMD CONSULTING, LLC

Anna Mracek Dietrich, S.B. and S.M. in Aerospace Engineering from the Massachusetts Institute of Technology, is a leading expert in Advanced Air Mobility (AAM) with over twenty years of experience in certification, regulatory affairs, and standards development. A licensed pilot and aerospace engineer, she co-founded Terrafugia, where she served as Chief Operating Officer and acting Chief Financial Officer, and later established AMD Consulting, LLC to support innovative certification projects across autonomy, eVTOL (electric Vertical Take Off and Landing aircraft), and unmanned aviation.

Dietrich has held senior roles with the Association for Unmanned Vehicle Systems International (AUVSI), the Community Air Mobility Initiative (CAMI), and Xwing, where she directed regulatory affairs for remotely piloted regional aircraft. She is an active contributor to a wide range of ASTM International technical and advisory committees on aviation, where she has over fifteen years of experience drafting, balloting, and managing technical standards, including serving on the executive committees of F44 and F37 and being part of the leadership of AC433 on eVTOL aircraft and AC377 for autonomous aviation. She has also supported rulemaking activities through the FAA Part 23 Reorganization Aviation Rulemaking Committee (ARC), the Beyond Visual Line of Sight (BVLOS) ARC, and Modernization of Special Airworthiness Certification (MOSAIC) efforts, and has worked with agencies such as National Highway Traffic Safety Administration (NHTSA), Environmental Protection Agency (EPA), California AI Resources Board (CARB), and MassDOT on aviation-related exemptions and certification projects. She has co-authored influential publications with ASTM AC377, and RTCA, and authored SAE Edge Reports, among others, addressing the operation and certification of electric and autonomous aircraft.

She is a frequent speaker at international forums such as South by Southwest (SXSW), AUVSI XPONENTIAL, and the U.S. Chamber of Commerce Aviation Summit, and has provided expert testimony to the U.S. House Committee on Science, Space, and Technology. Her contributions have been recognized by eVTOL Insights, Engineers Week New England, and the Boston Globe's "Top Innovators" list, establishing her as a trusted authority at the intersection of aerospace engineering, policy, standards development, and emerging aviation technologies. Dietrich also has a graduate certificate in public policy from the University of Massachusetts-Boston and is a private pilot.

JOHN MARIS, PHD., ADVANCED AEROSPACE SOLUTIONS, LLC

Dr. John Maris was the Principal Flight Test Investigator and test pilot for the NASA Traffic Aware Strategic Aircrew Requests (TASAR) and Digitally Enabled Cooperative Operations flight test programs. John holds Airline Transport Pilot Licenses from the FAA, Transport Canada and the U.K. Civil Aviation Authority (CAA), including single- and multi-engine land and sea, rotorcraft, and advanced flight instructor qualifications. He is a Fellow of the Society of Experimental Test Pilots with over 35 years of flight test experience and 6,700 flight hours in more than 85 aircraft types, including type ratings on several general aviation and transport category aircraft including the venerable Boeing 747 "classic." John Specializes in Control and Displays Human Factors, and he led the concept design of the Robotics Workstations that control the Canadarm2 on the International Space Station. His Human Factors contributions and innovations have been recognized by numerous aerospace awards, including an Aviation Week Laureate and induction into the Canadian Aviation Hall of Fame in 2018 for his role in "the transition to the paperless cockpit." He is currently Chief Test Pilot for CAE's Piper Archer electric trainer and Pratt and Whitney's Hybrid Electric Propulsion (HEP) technology demonstration program.

DR. RUTH STILWELL, AEROSPACE POLICY SOLUTIONS, LLC

Dr. Ruth E. Stilwell is an internationally recognized authority on integrated space and aviation policy, with a career that bridges operational expertise, academic scholarship, and high-level policy leadership. She is the Executive Director of Aerospace Policy Solutions, LLC, Adjunct faculty in the Master of Public Administration program at Norwich University, and served as a Senior Nonresident Scholar at the Space Policy Institute of George Washington University where her research focused on the common principles between guiding concepts for cooperative operations above Flight Level 600 (FL600) and emerging Space Traffic Management.

A 25-year veteran air traffic controller at the Miami Air Route Traffic Control Center, Dr. Stilwell served two terms in office as Executive Vice President of the National Air Traffic Controllers Association, was the founding Chair of the Air Traffic Services Committee of the International Transport Workers' Federation and from 2010 to 2015, she represented the global air traffic control community as the industry expert for air traffic controllers on the International Civil Aviation Organization (ICAO) Air Navigation Commission (ANC). During her ICAO work, she served as an ex officio member of the Unmanned Aircraft Systems Study Group (UASSG) and the Remotely Piloted Aircraft Systems (RPAS) Panel. This led to early engagement with the high-altitude operator community, including efforts by Google, Facebook, and AeroVironment to enable persistent operations above Flight Level 600 (FL600). In her current rule, she has spent the last decade conducting policy analysis and research for the aviation and space industries focused on the integration of new aviation entrants and commercial space operations in civil airspace.

In recognition of her contributions, Dr. Stilwell was named a Fellow of the Royal Aeronautical Society (FRAeS) in 2018. She also serves on the International Academy of Astronautics (IAA) Commission 5 – Space Policies, Law and Economics, and was elected as Academician to the IAA in 2025. Dr. Stilwell earned her BA in Labor Studies from the National Labor College, and both her Master of Public Administration and Doctor of Public Administration from the University of Baltimore where her research focus was on transportation policy and infrastructure resilience.

PAUL VAJDA, ADVANCED AEROSPACE SOLUTIONS, LLC

Paul Vajda works as a technical pilot and flight analyst, specializing in the coordination and execution of flight test and certification programs for modified aircraft. His professional background integrates operational flying, experimental flight test, and aerospace research. Paul Vajda is the lead author of the NASA-sponsored paper titled "A Systematic Approach to Developing Paths Towards Airborne Vehicle Autonomy", which addresses the integration of autonomous systems into the National Airspace System.

In addition to his research contributions, Paul has practical experience as a smokejumper pilot, operating Dash-8 and CASA 212 aircraft in Alaska and the lower 48, as well as several years of experience as a Certified Flight Instructor.

2. THE RESEARCH MOTIVATION

Advances in civil aircraft capable of operating without a pilot onboard create a mismatch between the existing human dependent flight rules and the capabilities of unmanned and autonomous aircraft. Civil Unmanned Aircraft Systems (UAS) are not currently permitted to operate routinely in unsegregated, controlled airspace[1]. The current regulatory approach to resolve this situation is to create category-specific flight rules, like FAR part 107, the Small UAS rule. Creating individual stand-alone sets of flight rules, based on aircraft category, does not provide a clear path toward integrated operations of civil UAS and is not consistent with the model that enabled the last century of flight. Existing routine operating modes, Visual and Instrument Flight Rules (VFR and IFR), are consistently applied regardless of aircraft type, operator, or mission profile, creating a stable and predictable system available to any user that meets established requirements. Non-routine operating modes, like those for parachute jumping operations, unmanned free balloons, and ultralight vehicles accommodate non-routine operations that cannot comply with IFR or VFR, but do so by limiting airspace access. Under the current regulatory approach, anticipated growth and diversity in UAS could lead to the proliferation of operation specific flight rules, increasing reliance on segregation, creating competition for airspace and stressing the existing air traffic control infrastructure. In contrast, a new Digital Flight mode would create an operator-accountable path to integrate routine UAS operations with IFR and VFR flights throughout the NAS, utilizing automated conflict management based on digital information and systems. The DECO research activity studied the option for any operators, who choose to equip and assume accountability for separation, using an alternative to IFR and VFR that could improve their operational safety and efficiency.

3. DECONSTRUCTING THE STATUS QUO OPERATING MODES

In addressing the elements needed for a new routine operating mode, it is important to understand the critical elements of the existing routine operating modes. The evolution of systems over time has served to build acceptance without the explicit analysis of the underlying concepts. As a result, there is no "playbook" for creating an operating mode.

Initially, we considered the need for flight rules to define the Digital Flight mode, considering the term Digital Flight Rules (DFR) [1]. While it is clear that flight rules will be needed to implement a new operating mode, as a non-regulatory research activity, the reference to rules became a distraction. Instead, "Digital Flight"

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[1] *Waivers or Authorizations, even those frequently issued, do not constitute routine operations. By definition, a waiver is an exception to the requirements of an operating mode and can be revoked.*

describes the functions and capabilities that would be needed for an operating mode that would be subject to regulation by an appropriate authority. These are described as essential elements and principal capabilities (PC) in the Digital Flight concept. Discussions on the need to quantify the performance of the PCs in order to establish appropriate separation minima led to the development of the Required Conflict Management Performance concept (RCMP) discussed in detail in a companion technical memorandum on the viability of Digital Flight [2]. This research deconstructed the existing operating modes, roles, responsibilities, and accountability at various decision points in the aviation safety chain [3]. Applying this approach, the separation provision function in conflict management (Appendix A) allowed us to consider where and how to introduce unmanned and autonomous systems into the decision-making process. However, doing so creates a need for new requirements to enable integration with systems that are dependent on human perception and decision making.

The primary distinction between the status quo operating modes, VFR and IFR, lies in the separation provision layer of conflict management. ICAO defines this layer as, "*the tactical process of keeping aircraft away from hazards by at least the appropriate separation minima* [4]." Separation services and airspace access in each airspace class are well defined and transparently communicated to the aviation community (Appendix B). The focus on separation provision in conflict management allowed us to examine the opportunities created by digital sharing of operational intent information. Digital tools allow for the sharing of intent with other aircraft, operators, and air traffic control (ATC) and enables the development of an airspace class-based framework for responsibility and accountability for separation provision that aligns with the other routine operating modes.

The goal of conflict management is the prevention of aircraft collisions with other aircraft or conflict with hazards. How that goal is achieved in a robust and dynamic aviation system reveals complex interactions between accountable human participants, with different perspectives on the task. The challenge of transferring certain tasks in the conflict management cycle from human to machine attracted these experts to the concept of Digital Flight. The diverse backgrounds of the authors as subject matter experts allowed us to examine conflict management from different perspectives. The systems view, tackling not just the design and development of necessary technologies, but how those technologies are integrated into existing systems and accepted by other actors in shared airspace requires viewing the research questions from different lenses.

Industry Context – *by Anna Dietrich*

Placing the DECO work in an industry context offers some key insights into how the research can have the maximum positive impact on aviation today and into the future. As increasingly autonomous aircraft technology is developed and operational pathways are explored, the most common approach is to try to adapt the existing operational rules – primarily 14 CFR 91 and 135 – to minimize or eliminate the necessity for humans to be active participants in flight operations. These efforts have focused, pragmatically, on the tasks performed by human pilots and how those tasks contribute to operational safety today. This approach has thus far come up short. While the list of specific paragraphs that pose a significant barrier to autonomous operations is small (20 identified out of 114 assessed in ASTM AC377's 3rd Technical Report "Regulatory Barriers to Autonomy in Aviation" [5]), even with these modifications, intuitively there is still misalignment.

The source of this misalignment has previously been obscure, with significant effort dedicated to the development of new Flight Rules (autonomous, digital, or otherwise) that would address the practical implications of human over-the-loop aircraft operations. Simultaneously, technology development for systems that could functionally act as drop-in replacements for onboard human pilots (e.g., detect and avoid systems, voice recognition software, machine vision image analysis) has advanced. The challenge of placing these systems and their accompanying aircraft autonomous intended functions into the existing airworthiness certification processes is another facet of the same fundamental disconnect. While on paper, it is possible to apply existing regulations to these new technologies, again, intuitively, there is hesitation.

The DECO and RCMP [2] work is critically important in that it gets to the root of this intuitive disconnect between the existing way in which current, human-centric aviation operations are handled and a future with increasingly autonomous operations. An interoperability pathway is also presented that allows new technology to share airspace with existing traffic. With a focus on measurable and tailorable performance metrics and a revised approach to accountability that is appropriate to autonomous operations, this work provides a path forward that is not just a procedural update but a prescient shift in how people and technologies work together to unlock safe and efficient aviation operations.

4. PERSPECTIVES ON CONFLICT MANAGEMENT

The experience of the project SMEs allowed for an in-depth examination of the underlying premise of conflict management from distinctly different stakeholder perspectives. This allowed us to approach the question with a well-rounded understanding and appreciation for the distinct motivations considered in each operating mode. The ICAO hierarchy detailed in the Global Air Traffic Management Operational Concept (GATMOC) [4] detailed in Appendix A explains the globally adopted recommended practice for describing layers of conflict management.

Variation in Conflict Detection and Resolution Systems - *by Captain William Cotton*

Conflict management is a term that covers the gamut of conflict detection and resolution strategies (CD&R), including short and long time horizons, strategic and tactical separation methods, cooperative and non-cooperative logic, and large and small nominal separation values ranging from tens of miles to hundreds of feet. At one end of the spectrum of conflict management, strategic techniques are widely employed by traditional, human centered air traffic services. Altitude and route separation can be used even in the absence of an active surveillance system. The term strategic conflict management is also applied to demand/capacity balancing techniques to prevent overload of constrained resources, such as airport runways. While this does not include actual separation distances among aircraft, flow rates and flow control management techniques comprise much of strategic conflict management.

At the other end of the spectrum is collision avoidance using time horizons of a minute or less ahead of projected Closest Point of Approach (CPA). TCAS has filled this role over the last three decades using primitive surveillance (providing range, range rate and altitude) to compute a vertical resolution maneuver designed to achieve a minimum of 400 feet vertical separation at the CPA. Visual separation, provided by pilots visually scanning the sky for conflicts, is another form of collision avoidance, seeing and avoiding other aircraft over a range of several minutes before CPA to last-second avoidance acting like a manual collision avoidance system.

Detect and Avoid (DAA) systems, as specified in RTCA DO 365C - Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems [6], provide a tactical separation provision service similar to TCAS and visual see and avoid but with longer time horizons using electronic means for surveillance, but still without trajectory intent or operating mode information on the traffic.

Comparison of DAA and TCAS

The continuum of traffic conflict management ranges from Strategic Conflict Management, with the longest "take action" time horizon, to Collision Avoidance using Detect and Avoid (DAA) algorithms having very short resolution times. Both systems perform the functions of CD&R. The differences between them lie in their alert times prior to CPA and their target separations at CPA. TCAS alert times vary depending on the altitude of the aircraft in the encounter, ranging from 20 seconds to one minute. The NASA developed Detect and Avoid Alerting Logic for Unmanned Systems (DAIDALUS) algorithms are the formal reference for the standard in RTCA DO 365C. It uses an alert time of several minutes and specifies a nominal horizontal and vertical miss distance that the logic attempts to maintain, while the TCAS standard uses a vertical-only minimum separation of 400 feet at the CPA.

TCAS logic was inherited from the Airborne Collision Avoidance System (ACAS) that used minimal surveillance parameters of range to the traffic, range rate (or closure speed), and encoded altitude, as these were the only information available using the "time/frequency" hardware design at the time. Contemporary surveillance using active interrogation of the traffic aircraft's transponder and ADS-B transmissions provides a measure of both the projected horizontal, as well as vertical miss distance at the CPA, giving rise to more complex algorithms to accomplish the CD&R function. Planned separation at the CPA may be increased from 400 feet vertical and zero horizontal for TCAS to thousands of feet horizontal and 500 or 1000 feet vertical, more akin to the separation provided by human controllers providing the Separation Provision function using radar separation procedures.

The parameters that make DAA similar to TCAS are the time prior to CPA when action is begun to resolve a detected conflict, a value called Tau in TCAS logic, and the acceptable miss distance at the CPA (4000 feet horizontal, 500 feet vertical). The DAA values are larger than the TCAS acceptable miss distance, and the maneuver is started earlier than TCAS as well.

Some have proposed that DAA systems can suffice as the sole means of separation provision for UAS operating in mixed airspace. There is precedent for that view as aircraft can operate under VFR in mixed airspace as the sole means of separation without being required to have TCAS as a safety backup. However, aircraft with 31 or more seats are required to have TCAS installed as a safety backup, whether operating under VFR or IFR. But when DAA is providing the separation provision layer, as opposed to the safety backup layer in the ICAO hierarchy detailed in the GATMOC [4], it must be held to a higher standard of performance, like other systems providing this function.

VFR was established in the distant past using "see and avoid" as the only means of separation provision available and it has not undergone a formal quantitative risk assessment. Similarly, IFR procedures have not been formally risk assessed, but would be expected to provide greater safety than VFR. Because DAA is an automated system, not involving human assessment of the traffic picture prior to its use for separation provision, a more formal method of risk assessment, and an agreed level of acceptable risk, must be used to gain its acceptance. DAA is not proposed as a substitute for TCAS, but rather as substituting digital means of CD&R for the visual means of remaining well clear of traffic, though without the use of intent information. Digital Flight provides for the inclusion of intent information and cooperative practices to build on DAA, but as both have CD&R functions, both should be subject to common approval requirements. Thus, the RCMP is applicable to DAA, which will allow the DAA contribution to conflict management to be quantified and given appropriate credit.

Digital Flight completes the conflict management continuum with DAA and TCAS at one end of the spectrum, and strategic techniques at the other. It is the tactical separation provision using additional information (e.g. operational intent) on the other traffic, whenever available, to dramatically improve the CD&R process. The self-separation automation would use the best available surveillance systems to obtain and apply not just state vector information, but tactical and strategic intent to filter out detected nuisance conflicts that disappear before requiring action, to resolve conflicts in the most flight efficient manner possible, and to cooperatively resolve conflicts with other similarly equipped traffic. This process would involve using a standard set of cooperative practices comprising the automated separation logic.

In summary, automated CD&R is not a "one size fits all" set of logic. Separation performance, for both safety and efficiency, is drastically impacted by the quality of the information input and the logic applied to that information to create conflict free flight guidance.

The Air Traffic Control and ICAO Lens – by *Dr. Ruth Stilwell*

Air Traffic Controllers have an in-depth perspective on conflict management, and it is a primary driver in the work of ICAO generally, and the Air Navigation Bureau (ANB) in particular. While the outcomes are transparent (safety performance, regulations, etc.) the inputs and processes of development of standards and recommended practices (SARPs) are less visible. In the DECO research, we identified several areas where conventional understanding of the conflict management process was imprecise and certain terms are conflated with one another. It is important to establish clarity in the use of terms for the development of a new operating mode. For example, separation provision and separation standards are distinct concepts. Separation standards reflect a collection of tools available for application by the entity providing separation services. Separation is also commonly conflated with radar separation leading to an erroneous assumption that separation services are not provided outside surveillance airspace. An important part of this work included clearly defining each element in the current processes and considering how operator-responsible separation can integrate into the existing airspace system.

Air traffic controllers take a systems view of the airspace and recognize conflict management as a continuum and may not have clearly distinguishable lines between the layers. They are responsible for the overall safety and efficiency of a volume of airspace regardless of the types of aircraft operating in it, and also rely on airspace design, traffic management, and automation to achieve that goal. This perspective informed my contribution to this work. Efficient use of airspace is the result of integrated operations where the focus is on separating aircraft from aircraft rather than separating aircraft from airspace or airspace from airspace. For the controller, a segregated airspace approach limits access to their most valuable resource – airspace. Concepts that rely on strategic conflict management alone, like corridors or volumes of airspace accessible only to certain operations, are inefficient and consequently increase workload. It is important to recognize that controller workload is a safety metric not an expression of productivity. For example, in certain airspace, advisory services to VFR aircraft are provided on a workload permitting basis. The reason for the workload permitting exception is to ensure that higher priority safety services are not impeded. The concept of a Digital Flight operating mode where operators have access to sufficient system information to assume accountability for separation provision, opens the door to greater safety and efficiency.

In addition to constraining resources, a purely strategic conflict management approach that relies on deconflicted airspace corridors is particularly concerning from an air traffic control perspective. Controllers are extraordinarily familiar with factors that affect an operator's ability to conform to a planned trajectory, particularly during convective weather or in-flight emergency situations. These are common events in the controller's workday. Controllers are predictably skeptical of any approach that cannot reasonably answer the question "what about weather?" For manned aviation, accountability and authorities are clearly defined and well understood, and responsibility can be transferred between the parties when appropriate. A system that places the burden on Air Traffic Control to "take over" separation responsibly if an autonomous flight cannot conform to its planned track is unworkable. The answer that a controller will take over responsibility is antithetical to a system developed based on a premise of accommodating scale that exceeds the limits of the human-based system. The approach where the human is the back up for automation system failures should be considered as a last resort by system designers, not as the first means to satisfy a safety case.

Separation Provision by Airspace Class

Understanding airspace classification and how it affects the responsibility for separation provision is essential to integrate a new operating mode into the NAS. The premise that Air Traffic Control (ATC) provides separation for IFR aircraft and the pilot provides separation in VFR is an oversimplification of the process. It is important to note that airspace class establishes both the ATC services provided and the entry requirements (equipment, communication, certification, etc.) to operate within that designated airspace. This is not the same as establishing the applicable separation standard. For example, while Class A airspace dictates that ATC separation services are provided and that all aircraft are IFR, it does not dictate whether separation is radar or non-radar (surveillance or procedural).

The DECO research operated under the assumption that the Digital Flight operating mode is intended for use in any airspace class, by any type of operator choosing to use it. However, that does not mean that no requirements will apply. Like the other routine operating modes, we expect the operational requirements and services provided for Digital Flights will be clearly defined for each airspace class.

Separation Standards

Airspace class dictates which separation services are provided but does not dictate the separation standard to be used. Separation standards are based on the performance of Communication, Navigation, and Surveillance (CNS) of the airspace and the aircraft systems, and the physics of the encounter. For example, Required Navigation Performance-4 (RNP4) and half-track separation was developed to meet demand in the North Atlantic (NAT) and Asia and Pacific (APAC) regions by implementing performance-based separation that includes Performance Based Communication and Surveillance (PBCS) illustrated in Figure 1 [7]. The concept of performance-based separation, building on performance-based navigation, required the development of measurable performance standards for both communication and surveillance [8]. However, as the process for creating new separation standards is both demand driven and lengthy, use of the lowest common denominator is often the default approach. Industry economics plays a role in the development of separation standards and generally there is not a will to require new equipment unless there is a corresponding measurable benefit to safety or need to increase capacity. Controller skill, experience, and workload can also be implicated in the choice of separation techniques applied in a particular encounter. Some separation tools available to apply smaller than routine separation standards require additional transmissions with precise phraseology that can be time consuming and increase frequency congestion.

PBCS approval required to be eligible to participate in the following horizontal separation minima in accordance with ICAO PANS-ATM (Doc 4444):

Dimension of separation	Separation Minima	RSP requirement	RCP requirement	Associated navigation requirement
Lateral	42.6 km (23 NM)*	180	240	RNP4
Performance-based Longitudinal	5 minutes	180	240	RNP2 or RNP4 or RNP10
Performance-based Longitudinal	55.5 km (30 NM)	180	240	RNP2 or RNP4
Performance-based Longitudinal	93 km (50 NM)	180	240	RNP4 or RNP10

* Also applicable to existing and future applications of 30NM lateral separation minima

Airspace using or planning to use one or more of the above
- PAC FIRs: Anchorage, Auckland, Brisbane, Fukuoka, Nadi, Oakland; Port Moresby, Santiago, Tahiti,
- NAT FIRs: Gander, Shanwick, Reykjavik, New York, Santa Maria
- Bay of Bengal routes: M300, N571, P570, P574; L301, L507, L510, L759, M770, N563, N877, N895, P628, P646 and P762
- South China Sea routes: N892, L625, N884, M767

Figure 1: FAA PCBS to implement ICAO Performance Based Separation (Source: FAA [7])

The approach to developing new separation standards is historically reactionary – evaluate the capability of the available technology then determine the separation standard required to mitigate the risk from performance error. For example:

> **Procedural (non-radar) -** The interval between position reports, the potential error in navigation, and variation in speed creates the uncertainty metric that is accommodated in the separation standard. The largest separation standards apply when navigation is imprecise and both surveillance and two-way communication are limited. As each improves, the applicable separation minima are reduced (Figure 1).
>
> **Radar (surveillance)–** In areas with adequate surveillance and communication, the update rate and distance from the antenna are determinates of the separation standard. Reductions in the minima are generally achieved through improvements in onboard systems, requiring both provider and operator investment in equipment and/or training, like Reduced Vertical Separation Minima (RVSM) or Precision Runway Monitor for closely spaced parallel approaches. It is notable that the implementation of ADS-B, providing greater position certainty, did not create a reduction in the 3- or 5-mile radar standard, argued in part because the wake turbulence requirements for safety necessitate a larger standard than the equipment performance may allow. From a more practical perspective, once ADS-B was determined to perform well enough to apply the radar separation standard, there was not sufficient demand from the operator community to justify the investment in the development of new surveillance separation standards.

The approach of developing a separation standard that reflects the performance of the system is the basis for the legacy system of prescriptive standards. Moving forward, the desire for a performance-based regulatory framework that is technology independent requires a shift in the approach that allows for the development of the performance standard to which the technology can be designed. It is a change in the question from "what does the technology allow us to do?" to "what do we need the technology to do to allow us to achieve this goal?" For Digital Flight, this is an important distinction and opens the door to benefits-driven performance standards that are responsive to operator needs and willingness to invest. The challenge then shifts from the capability of an individual aircraft to the acceptance of the operation of that aircraft in shared airspace.

The concept of RCMP [2] within the DECO activity provides the means for operators to demonstrate their safety case to the regulator to allow smaller separation standards specific to their capabilities. This approach aligns with statements in FAA future concepts [9] [10] [11]. This can incentivize investment in research and equipment that allows the system to move away from a limited set of available separation standards based on the lowest capable aircraft in shared airspace. In addition, shifting the burden for the development and modeling of operation specific separation minima from the government to an industry-based standards making process creates an opportunity for operators to tailor investment into standards and equipment that meet their needs. The airspace community has accepted the VFR separation value of "well clear" based on the independent judgement of each pilot in command for more than a century. The transition to an operator-defined, automation-performed, government-approved, value is an enhancement to, not a degradation of, the status quo.

For the controller, the overriding issue is not how the approved separation minima were developed, but rather what is the applicable minima to be applied and who is the accountable entity to ensure that separation is maintained? The concept of separation provision is further broken down to identify the separator and apply terminology to ensure accountability is unambiguous (Table 1).

It is important to note that in this table the ICAO term "cooperative separation" describes the condition referred to in the US as delegated separation. The use of the term "cooperative" in concepts like Upper Class E Traffic Management (ETM) or DECO refer to the interaction between operators using approved cooperative practices to enable automated processes and does not use the ICAO definition of "cooperative separation." In addition, the ICAO Global Air Traffic Management Operational Concept (GATMOC) [4] uses the term "airspace user" in describing the accountable separator. Our Digital Flight research consistently uses the term "operator" to maintain a positive connection to the operation of a specific aircraft and to avoid ambiguity with other applications of the term "user", like special use airspace delegated to a "Using Agency."

Table 1: Separation Provision (data source: ICAO)

SEPARATION PROVISION	
self- separation	The situation where the airspace user is the separator for its activity in respect of one or more hazards. (GATMOC 2.7.23) Full self-separation is the situation where the **airspace user is the separator** for its activity in respect of all hazards. In this case, no separation provision service will be involved; however, other ATM services, including strategic conflict management services, may be used. (GATMOC 2.7.24)
distributed separation	Occurs when, for an airspace user's activity, there are **different separators for different hazards**. This can be because different predetermined separators have been defined or because delegation of separation has occurred. (GATMOC 2.7.25)[2]
***cooperative separation* (in the U.S. the term delegated separation describes this condition)**	Occurs when the **role of separator is delegated**. This delegation is considered temporary, and the condition that will terminate the delegation is known. The delegation can be for types of hazards or from specified hazards. If the delegation is accepted, then the **accepting agent is responsible for compliance** with the delegation, using appropriate separation modes. (GATMOC 2.7.26)
separation provision service	Available when safety or ATM design requires. (GATMOC 2.7.27) Full separation provision service occurs when the **service provider is the separator** for an airspace user's activity from all hazards. (GATMOC 2.7.28)

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[2] *For example, an aircraft operating IFR, the air traffic controller is responsible for separating the aircraft from airspace and other aircraft, but the pilot retains responsibility to separate the aircraft from hazardous weather.*

Conflict management is not a synonym for separation provision or separation standard. The concept is complex and cannot be reduced to a single value. A digitally dependent operating mode must consider the breadth of contributions, both technical and regulatory, that are necessary to achieve the intended outcome.

Adjunct Performance Based-Concepts within Digital Flight – *by Paul Vajda and John Maris*

Digitally enabled cooperative operations rely on a level of system autonomy greater than required for today's VFR and IFR operations. Since Digital Flight is an operator-based, automated separation enabled operation, the operator must then have the information required to make navigational decisions that keep it safely separated from other traffic. At the same time, the operator must possess the ability to make informed navigational decisions based on the requisite information. This section discusses two performance-based concepts that support the development of digitally enabled cooperative operations in lieu of their current prescriptive equivalents.

Digital Flight Visibility

In Digital Flight, aircraft operators are not dependent on ATC for separation. Therefore, aircraft must be capable of maintaining separation from other aircraft independently, while simultaneously calculating a trajectory within navigational constraints such as terrain, obstacles or hazardous weather. Digital Flight Visibility (DFV) would be the ability to maintain awareness of these trajectory constraints at all times.

DFV parallels the concept of Required Navigation Performance (RNP), which specifies the precision, reliability, and availability requirements for navigation systems to operate within specific airspace or on certain routes or approaches, and establishes performance standards for the entire suite of onboard sensors and databases used for navigation. Similarly, DFV specifies the minimum system performance standards for the combined sensors, databases, and datalinks that supply the digital "visibility" function, and does not focus on a single sensor, such as the human eyeball, to specify the flight visibility.

DFV is the average time (or distance) horizon from the aircraft's present location, that an operator can detect terrain, traffic, weather, and obstacles based on a combination of static (database), on-board real time (sensor) and external (datalink) data. Different data sources are combined so that deficiencies in accuracy, timeliness, completeness and availability from one data source may be covered by another. For example, doppler radar for turbulence detection cannot detect turbulence without the presence of liquid water and is therefore blind to clear air turbulence. Another data source is therefore required to fill the gap.

Capability Margins

Autonomous or uncrewed vehicles must be able to make trajectory choices based on the relationship between the vehicle capabilities and the demands of the environment. For instance, a vehicle with no ice protection systems must avoid areas where icing conditions exist. Vehicle capability, then, is defined as a vehicle's capacity to respond to the environment in which it operates. A capability margin is defined by comparing the available system capability with what is required by the environment. The concept is best illustrated by example:

1. Performance Based Navigation (PBN) and RNP specifications detail required positional precision in nautical miles depending on where the aircraft is operating. Actual Navigation Performance (ANP) is the positional precision achieved by the pilot/vehicle system in real-time. In this example, the navigation system's precision capability margin is the difference between the RNP and the ANP.
2. Flight into icing conditions requires the ice protection system be capable of protecting the airframe from ice accumulation for the entire duration of the icing conditions. For an aircraft with weeping wings, the capability margin is driven by the amount of available fluid and the ice accretion rate. The margin can be expressed in minutes or miles of remaining range.

An example of capability margins is the Available Power Profile (APP), which is of relevance to electric aircraft. Contrary to conventional fuel, available battery power decreases as battery energy is depleted, implying maneuvers with a high energy demand such as hovering may not be achievable after a certain amount of flight time. Available Power Profile defines how the remaining energy can be allocated. This is an important concept for electric vehicles, since the instantaneous and future available power depend on at least the present and past rates of discharge. For example, consider an electric vehicle is operating in icing conditions and must activate its electrically powered ice protection system. The additional drain on the battery system accelerates battery energy depletion and lowers the maximum power output impacting cruising speed, maximum hover time, or the ability to hover outright.

The concept is equally applicable to conventionally powered aircraft, but the co-dependance of energy level and power output makes the APP particularly relevant to electric aircraft systems.

Application of DFV and capability margins requires large datasets be organized in a searchable, relational framework. Data models such as the Aeronautical Information Exchange Model (AIXM) or Weather Information Exchange Model (WXXM) are established and open source. An ontology has also been developed for this purpose and serves as a knowledge base for a decision-making system in the context of navigational decision making [12].

Deconfliction Strategies

Successful implementation of DFV and Capability Margins entails a re-examination of the 14 CFR 91 current see-and-avoid rules, which have their origin in pre-aviation seafaring days. Effectively, the basic deconfliction options available to aircrew under VFR are to maintain course if in the right-of-way, or turn right to give way to other traffic. With the exception of TCAS Resolution Advisories, vertical maneuvering is not envisaged as a means for deconfliction under Part 91. Removing this constraint would allow Digital Flight to consider both vertical and lateral deconfliction options to optimize aircraft trajectories while maintaining safe separation.

5. DEVELOPING FUTURE ALTERNATIVES

The FAA is responsible for balancing the interests of all airspace users in ensuring aviation safety in the interest of aviation stakeholders and the American public. This balance is not achieved by either relegating new entrants to marginal airspace or by imposing new burdens on legacy operators to accommodate those new entrants. The processes of developing alternatives to the human centric operating modes is not an activity in support of one operator type or another, but rather in pursuit of this overall mission.

Operating Modes in the NAS

Every aircraft operates within a set of rules and procedures that define the means to operate safely within the airspace. The most common operating modes are routine IFR and VFR. Both are widespread and commonly understood. In addition to the routine IFR and VFR operating modes, there are several specialized operating modes created to accommodate operations that cannot conform to the requirements of VFR or IFR, due to aircraft limitations or mission requirements (Table 2).

Each of the current operating modes are dependent upon human situation awareness, perception, and decision making. Automation tools are categorized as decision support for the human performing separation provision[3].

Table 2: U.S. Operating Modes

Routine Operating Modes
Visual Flight Rules
Instrument Flight Rules
Widespread ***use in most airspace classes***   ***Routine*** ***for pilots and controllers***

Specialized Operating Modes
State/Military Aircraft operating "Due Regard"
Unmanned Free Balloons
Ultralight Vehicles
Parachute Operations
Small Unmanned Aircraft Systems
Limited *to certain operations and/or airspace incompatible with IFR or VFR*   *Routine* *for pilots who use them;* *non-routine* *for controllers and other pilots*

[3] *In the collision avoidance layer, a TCAS Resolution Advisory (RA) goes beyond the category of decision support, instructing the pilot to take evasive action. However, even in the case of a TCAS RA, there are provisions for pilot intervention in the collision avoidance decision [30].*

Digital Flight envisions an operating mode that authorizes flight by reference to digital information, shared intent information, and encoded practices, in lieu of human perception. The separation function lies within the construction of the operating mode. Designing a routine operating mode without the presumption of human intervention allows for the establishment of system performance standards to ensure a designated target level of safety (TLS) is met and shared digital information allows for continual monitoring of Digital Flight performance, relative to the TLS.

Integration in Controlled Airspace

The goal of fully integrated airspace is expressed in the FAA's Info-centric NAS (ICN) initial concept of operations [13], NASA's Sky for All [14], and the FAA's formal Vision statement "*We strive to reach the next level of safety and efficiency and to demonstrate global leadership in how we safely integrate new users and technologies into our aviation system*" [15]. As the existing routine operating modes are dependent on human perception, an operating mode that allows for digital operations to fully integrate into the airspace must address more than the required separation standards. The operating mode must consider how Digital Flights will interact with IFR and VFR traffic, who is accountable for the performance of automated systems, and how traditional aircraft that are not connected to an information sharing system can reasonably anticipate the behavior of a Digital Flight aircraft.

The need for other aircraft to anticipate behavior, whether or not they are aware of the operating mode of another aircraft, is necessary for integration. Consider existing flight in Class E airspace. The VFR pilot is accountable to see and avoid all other traffic and may not be aware of whether the traffic is IFR or VFR. The air traffic controller, providing separation services to IFR traffic, may or may not be in contact with VFR traffic, but can reasonably anticipate the behavior of VFR traffic not receiving ATC services (based on Rules of the Air) in determining an appropriate course of action. The behavior of traffic operating under a Digital Flight mode should behave in a similarly expected manner to integrate into existing airspace. The stability of a routine operating mode designed to be integrated across the NAS provides this element. In contrast, a series of bespoke operating modes introduces uncertainty as other operators may not be aware of which mode traffic may be operating under, limits the ability to reasonably anticipate behavior of other aircraft.

Integrating a new automated operational paradigm is a different challenge than integrating a new automation tool that supports the human decision maker. Historically, the integration of new equipment or development of new separation standards includes operational trials, using a controlled environment to demonstrate the feasibility and safety of new operations and procedures. The obligation to protect the safety of uninvolved aircraft may rely on the use of segregated airspace for the trials to exclude non-participating aircraft. However, this use of segregated airspace is a temporary condition limited to the approval process. Once approved, new tools are integrated into unsegregated airspace.

The operational trial occurs at the end of the approval process, after the research, modeling, and simulation phases, and is limited in duration and scope. However, for new models of flight, like unpiloted and autonomous operations, the operational trial approach may not provide sufficient operational information.

Other approaches, like those used in the Small UAS example, where the FAA relied on six designated test sites in developing its UAS traffic management concept (UTM), to collect operational data in different geographic and climatic regions [16] were necessary to prove the concept.

The research team examined alternatives to a new operating mode. An exploration of those alternatives is explained below.

ALTERNATIVE 1: MODIFY EXISTING FLIGHT RULES

With the exception of Remotely Piloted Aircraft Systems (RPAS) operating under the IFR flight mode, this approach was considered impractical and could introduce new safety risks. The number of rules that would require modification would place a considerable rulemaking obligation on the FAA and if not harmonized with ICAO, would add an additional reporting and publication burden for differences and variances as illustrated in paragraph GEN 1.7 of the Aeronautical Information Publication (AIP) [17]. This option is used to accommodate certain US specific procedures as the ICAO process to amend an annex is lengthy and resource intensive.

The operating rules for IFR and VFR are well known and understood by pilots, controllers and aircraft dispatchers. The stability of the system is the basis for a historical safety record far exceeding that of other modes of transport. Changes to existing rules and procedures affect the entire certificated community and its training organizations and institutions. According to the FAA 2024 Active Civil Airmen Statistics [18], the U.S. has 848,770 active pilot certificates, which includes more than 300,000 student certificates. Other than students, there are 172,012 private pilot certificates, 109,727 commercial certificates, and 179,194 airline transport certificates. According to FAA's air traffic controller workforce plan, in 2023 there are 13,448 air traffic controllers employed by the FAA [19]

In contrast, the creation of a new optional operating mode requires certification and training only for those that elect to use it. As an illustration, a VFR pilot is not required to train and certify on changes to IFR, and airline transport pilots are not required to train and certify on changes to FAR 101 or FAR 107. Limiting the workforce affected by changes reduces the cost of rulemaking and disruption to the industry. In the non-pilot community, the existing group most affected are air traffic controllers, who are required to be proficient in the flight rules, roles, and responsibilities for all aircraft authorized to operate in the airspace they manage.

The dependence on the human for interpreting and transmitting information and decision making is pervasive throughout both IFR and VFR regulations. It is clear that the ICAO decision to narrow its focus for Annex 6: Operation of Aircraft, Part IV to remotely piloted aircraft, where the human pilot retains the Pilot in Command (PIC) responsibility for interpreting information and making operational decisions, reflects the complexity of the regulatory mismatch between a system designed around human perception and aircraft that can operate without human intervention. The Annex provides standards and recommended practices for IFR flight, ensuring that the accountability for separation provision lies with ATC. While it is a step forward, it takes that step in a manner that is least disruptive to the existing routine operating modes. It is unclear how this approach can be effectively expanded beyond remotely piloted IFR flight to other UAS operations. It is also important to note that the RPAS Panel, the expert group at ICAO tasked with developing the new standards, was formed in 2014 and worked continuously toward RPAS integration leading up to the 2024 adoption of the Annex to be applicable in 2026 – a 12-year process. In addition to the provisions for certified UAS to operate under IFR in the existing ATM system, the Annex provides for states to develop regulations for other unmanned operations where interactions with manned aviation are infrequent. The DECO research team considered the ICAO language carefully and believes that it creates an opportunity for FAA to authorize digital operations in unsegregated airspace where interaction with manned aviation is infrequent but not precluded, while work toward an appropriate operating mode is researched and developed.

ALTERNATIVE 2: RESTRICT OPERATIONS TO AIRSPACE CORRIDORS AND VOLUMES

Expanding the airspace corridor approach preferred for UTM was similarly evaluated and not selected as a viable path toward integration by the research team. The segregated airspace corridor captures the strategic level of conflict management but does not extend to the separation provision (tactical) layer. Reliance on segregated airspace is an inherently inefficient airspace management tool. It relies on the premise of separating airspace from airspace rather than aircraft from aircraft and does not provide flexibility to avoid local hazardous weather. While strategic separation is an essential part of the conflict management continuum, strategic separation alone does not provide a path toward full integration in shared airspace (Figure 2).

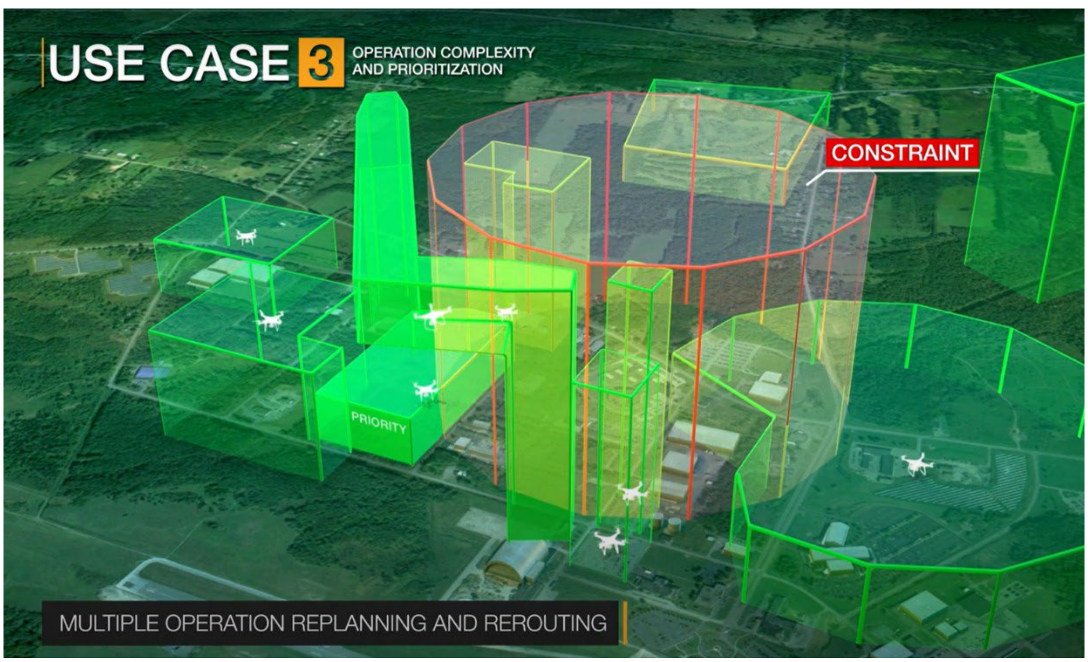

Figure 2: UAS Flight Test New York Use Case 3 (Source FAA animation)

On the surface, programs like the FAA UAS Data Exchange provide a path to integration. However in its initial implementation of the Low Altitude Authorization and Notification Capability (LAANC), the term integration is used in connection with an authorization to fly in controlled airspace below 400 feet, but does not provide exclusive use of the airspace, separation services, or relieve the drone operator of any obligations under FAR Part 107 [20].

At scale, the airspace corridor approach would require significant automation support and potentially assignment to individual corridors by a third-party service provider. It is unclear where the transition point occurs when the use of protected airspace corridors effectively becomes procedural air traffic control, particularly if operators are dependent upon a third-party service provider. At that point, the third party effectively becomes an Air Navigation Service Provider (ANSP) imposing a new obligation on the FAA to serve as an external ANSP regulator and would require an airspace delegation or challenge the well-established principle that only one ANSP can be responsible for providing services in a given volume of airspace.

ALTERNATIVE 3: INITIATING RULEMAKING FOR EACH SPECIALIZED OPERATING MODE

This alternative captures the status quo approach rather than assessing emerging research. The development of FARs 107 and 108 reflect this approach. Often research jumps to operating concepts designed specifically for the type of operation being developed. As shown in table 2, specialized operating modes are the default means to accommodate aircraft that cannot comply with routine operating modes (IFR or VFR). Historically, these are also marginal users. The concept of large scale, commercial UAS operations anticipates routine operations at the scale of IFR and VFR. As UAS vehicles become larger, and flights are more frequent and diverse, the ad-hoc regulatory approach becomes unworkable from both a systems and regulatory perspective. A proliferation of operating modes may also carry operational safety concerns, but the issue has not been adequately studied to form a definitive conclusion. As the status quo approach, it has not been subject to the analytical rigor that is applied to new proposals. However, that does not imply that it is a superior or low risk approach, only that the study has yet to be undertaken.

ALTERNATIVE 4: NEW OPERATING MODE DESIGNED FOR NAS-WIDE INTEGRATION

An approach that is interoperable with existing systems and doesn't require modification to the current stable operating modes has distinct advantages over the modification of existing flight rules (Figure 3). From a rulemaking perspective, a comprehensive approach that can be applicable across aircraft or operator types allows for the development and integration of new technologies with a measure of regulatory certainty that if the operation meets requirements, it can be approved. An operating mode that does not rely on segregated airspace provides greater flexibility and access to airspace for all operational types. It is important to ensure that one operating mode does not displace another in competition for airspace. A digital operating mode allows for the same type of routine use of airspace that has allowed both IFR and VFR to flourish. This can provide a stable model for growth that not only accommodates innovation but allows the entire system to benefit from innovation in Digital Flight. The DECO research activity adopted this approach to provide a model that is sufficiently suitable and flexible to meet the needs of the second century of flight.

Existing routine operating modes, IFR and VFR, are not designed for operations without a pilot on board. While ICAO standards in Annex 6 – Part IV have been adopted for UAS operations under the IFR operating mode [21], efforts to allow operator-accountable UAS conflict management rely on the development of new specialized operating modes. Using dedicated US regulations specific to an aircraft category, like the sUAS rules in FAR Part 107 [22], conveys a framework that limits access to certain airspace categories, may exclude operations in international airspace (even where the US is the ANSP), and relegates aircraft of certain types and size to the margins of airspace access. This approach is inconsistent with routine operating modes that base airspace access on the capability to meet entry requirements, notwithstanding the aircraft type or size. Rather than an integrated approach, Part 107 restricts the operation of the specific aircraft type. A new routine digital operating mode that permits an operator to provide conflict management based on digital information follows the approach used for the routine IFR and VFR operating modes. This provides a path to full airspace integration and enables scalable operations of digitally enabled aircraft whether or not there is a pilot onboard.

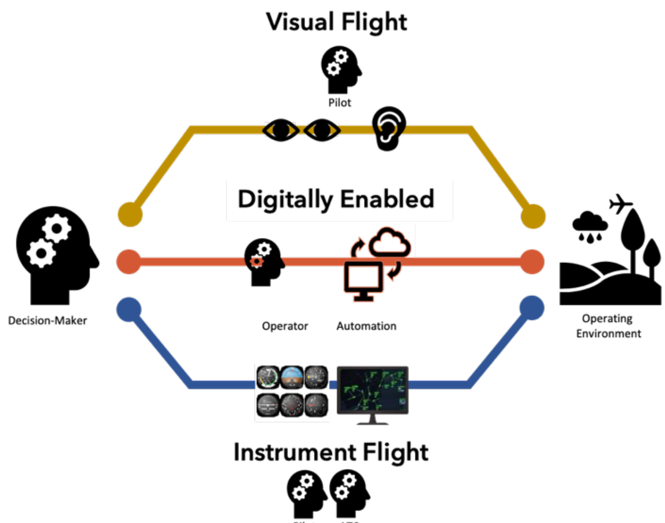

Figure 3: A digitally enabled operating mode interacts with IFR and VFR modes

6. A RESEARCH FOCUS ON DIGITALLY ENABLED COOPERATIVE OPERATIONS

Digital Flight moves aviation beyond the twentieth century limitation of radio communications to one that takes full advantage of machine-to-machine communication, connected aircraft, and the concept of an Info-Centric NAS [13], capitalizing on the information age. This is a transformative opportunity. Operator-responsible separation, whether it is VFR see and avoid or emerging detect and avoid (DAA), relies on inferred information from state vectors. The absence of intent information infuses inefficiency in the system as it precludes strategic conflict management and requires consideration of the uncertainty about the behavior of the traffic being avoided. Digital Flight overcomes this limitation by sharing intent that is available to diverse NAS stakeholders including air traffic control, traffic flow management, and other connected aircraft and operators.

As the concept of Digital Flight was refined, responding to input from stakeholder engagement and internal NASA feedback, the nomenclature changed to reflect the specificity of "operator-based, automated separation provision" leading to the use of the term digitally enabled cooperative operations (DECO). This focus did not change the underlying principles of Digital Flight but provided clarity that the research focus is on the requirement and accountability for the separation provision function and not inclusive of other digital functions related to the operation of the aircraft (i.e. command and control). This led to the development of concepts detailed in two complimentary NASA technical memos, one on Required Conflict Management Performance [2] and one on Accountability in Automated Self Separation [3].

Analyzing accountability at each point in the chain of decisions and actions to achieve the desired outcome (target level of safety) proved instrumental in progressing this research. For example, an automated separation system that obligates a pilot to a prescribed course of action cannot rationally assign accountability for that action to the pilot, as the pilot is constrained by the system. Conversely, a decision by the pilot to disregard the instructions of the automated separation provision system is an assumption of accountability, because disregarding the automated instruction is a decision point wholly within the control of the pilot. Similarly for air traffic controllers, it is not rational to assign accountability for actions of the system over which the controller has no ability to affect. Accountability is tied to decision points and the entity exercising the decision authority. However, accountability cannot be assigned to a system; there must be an accountable human entity to complete the safety chain. For an automated system, human accountability occurs before the operational decision. Systems are approved and configured by humans, meeting established performance requirements developed by humans, a human operator is accountable for installing, operating, and maintaining the systems according to regulations, etc.

Defining capabilities in terms of Conflict Management was an essential part in understanding responsibility, authority, and accountability in Digital Flight. The Principal Capabilities (PC) of Digital Flight [1] helped refine the DECO activity and align with the ICAO defined layers of conflict management. The first three principal capabilities, operator self-separation, shared separation, and pairwise coordinated separation, align with the separation provision layer of conflict management. The remaining three principal capabilities, constrained resource collaboration, self-organization, and self-limiting density/complexity, align with the strategic conflict management layer. This alignment highlights operational benefits of Digital Flight that go well beyond enabling VFR-like operations for unmanned aircraft. The organic alignment of the PCs with the conflict management layer reinforced the validity of the approach.

The Evolution of Digital Flight – *by Captain William Cotton*

This author had conceived of using operator-based autonomous separation in all weather conditions while writing his master's thesis in 1965. At that time, only ground-based radar existed as a surveillance tool and computing was in its infancy, so he proposed sending the radar picture to the cockpit to be displayed on a TV receiver for the pilot to use in manual separation tasks, such as following another airplane to the runway. He later found that Mr. Crocker Snow of the Massachusetts Aeronautics Commission proposed the same thing while working at RCA in 1947. Two master's students who followed me at MIT took the concept into simulation using a fixed base cockpit simulator provided by Boeing after they shut down their supersonic transport (SST) program. They first called it an "Air Traffic Situation Display" (ATSD) and later a Cockpit Display of Traffic Information, or CDTI. Automation of the separation function was not part of this early work.

In 1971, the author wrote a paper for the IEEE publication "Transactions on Communications" on this subject that expanded the concept from manual to automated conflict detection and resolution. The paper defined when a conflict would begin and cease to exist. It also defined how much maneuvering would be required to resolve conflicts, when that maneuver should begin, and distinguished between positive and negative conflicts in which positive ones required maneuvering off the current trajectory and negative ones required maintaining the current trajectory until the time when free maneuvering was once again available.

But automated conflict management really had its origin in the earliest attempts to create electronic collision avoidance. In the mid-1950's John "Smiley" Morrell at Bendix Radio proposed a simple logic to determine when action needed to be taken to avoid a collision threat. Dividing the range to the target by the range rate (its closure speed) yields the instantaneous time to closest approach. When this time, assigned the Greek letter Tau, reached a value twice the time needed to resolve the threat, an alert would tell the pilot what action to take. Ranging was first tried with a ground bounce system that compared the time difference between a direct transmission and one bounced off the ground. Another system, called Eliminate Range Zero System (EROS), required all aircraft to carry expensive atomic clocks that were synchronized to measure distance by time delay. The McDonnell Company used ACAS on their test aircraft in restricted airspace to prevent collisions, but it was too expensive to equip all civil aircraft with this system. However, the Tau criterion survived as a means of detecting conflict in all later collision avoidance development, including TCAS.

TCAS development addressed a safety backup to air traffic control but was not proposed as primary separation guidance. In 1975, MIT Lincoln Labs had a project they called Electronic Flight Rules (EFR), that sought to advance the automated separation concept with then available technologies. This author assisted in design of EFR cockpit display to assist the pilot in the proposed operation. Unfortunately, the necessary technologies were not sufficiently advanced for it to catch on and it ended with a report. The ATC transponder was used in the TCAS development, using active interrogation by the protected aircraft and the encoded altitude from the Mode C transponder on the traffic aircraft to filter the traffic of interest. When FAA Administrator, J. Lynn Helms formally called for the development and implementation of TCAS in 1981 [23], it was a policy decision accepting the idea of Operator-Centric, Automated Conflict Management in some circumstances. Those circumstances were limited to imminent near mid-air collision, in any class of airspace, in any type of aircraft operation. That policy decision was so revolutionary that it took both a congressional mandate [24] and the FAA Administrator signing the Order to require implementation of TCAS on all aircraft with 31 seats or more [25].

TCAS was a good solution for a last second maneuver to prevent a collision, but the need for more IFR efficiency and greater VFR safety got stronger every year so the work on automated separation continued throughout the 1980's. FAA looked into a concept called Intermittent Positive Control, or IPC, in which flights would be free to proceed without a clearance until a conflict arose at which time they would be controlled by ATC to resolve the conflict. This was never implemented, but FANS 1, pursued through ICAO (International Civil Aviation Organization), was developed and implemented, relieving much of the inefficiency of oceanic strategic separation.

The continuing inefficiencies of domestic IFR flights and the remaining collision risk in smaller General Aviation aircraft prompted this author to propose to the FAA a concept called FreeFlight in 1995. IFR flights are generally approved on "ATC Preferred Routes," designed to minimize workload for human controllers managing the traffic in their sectors. All aircraft operators would prefer to fly the "best wind route", a least wind-mile, dynamically changing path between origin and destination. This yields the lowest flight time and least fuel burn. FreeFlight proposed that any removal of a restriction to flight (e.g., traffic management initiative) was a move toward FreeFlight, but ultimately, all aircraft should be able to self-separate and self-space to the runway at destination. ADS-B and TCAS were to be the sources of surveillance in this concept.

FAA adopted the idea initially and formed an FAA/industry FreeFlight steering committee to hold the FAA accountable for its development. But the FAA mandate for ADS-B to be required in the same airspace as the transponder gave aircraft owners until 2020 for compliance, so the FAA turned their attention to an expanded ground equipment modernization program called NextGen. Also, after the attacks of September 11, 2001, the airlines sent their technical, management pilots back to flying the line and the industry support for FreeFlight evaporated. Fortunately, a small project at NASA called Distributed Air/Ground Traffic Management (DAG-TM), survived.

In this concept, traffic and intent information was to be shared among the aircraft, the airline operations center, and ATC. Aircraft could make separation decisions on their own and follow preceding traffic to the destination runway. Research focused on the necessary enabling technologies and was shared with the Netherlands research center that was working on the same thing. Operator Centric, Automated Conflict Management, both strategic and tactical CD&R algorithms, were developed and coded into software called the Autonomous Operations Planner (AOP) and were tested in piloted simulations at NASA. Other software, called Interval Management, gave speed guidance to flight crews to enable precise following distances among aircraft in trail to a destination airport runway.

The AOP software was designed for use in Class A airspace by airlines. But as the aircraft population was still without ubiquitous ADS-B OUT, NASA researchers turned their attention to a nearer term project that could provide efficiency gains to airline operators in a concept called Traffic Aware Strategic Aircrew Requests (TASAR).

TASAR focused on the flight optimization software monitoring flight conditions and proposing changes in route and/or altitude that would yield fuel and/or time savings. The proposed changes were checked by the AOP software to ensure that they would not create a traffic conflict, using ADS-B IN for traffic awareness. The pilot would then make a request to ATC for the trajectory change. Most airline flights are filed on ATC preferred routes to be accepted onto the En Route Flight Data Processing (FDP) system, but sufficient flexibility exists once airborne for route change requests to be routinely granted. NASA made the TASAR software publicly available for licensing, and it has been commercialized. TASAR still needs human intervention to use the outputs of the TASAR automation.

But the broader need remained to provide an alternative to IFR restrictions, to include all users of the airspace, and to turn the focus on the flight rules to differentiate how equipped operators could fly. NASA pursued the goal of autonomous flight and automated conflict management under the concept of Autonomous Flight Rules (AFR). Integration with terminal procedures was added, coordinating with ATC automation for Traffic Flow Management metering assignments. AFR also includes Interval Management for terminal in-trail spacing. As this was no longer part of either VFR or IFR, that implied the existence of a new operating mode. This full airborne control of conflict management from takeoff to touchdown later became refined into a practical roadmap for implementation called Airborne Trajectory Management (ABTM).

The roadmap of logical implementation steps began with TASAR and progressed through datalink requests for trajectory change to the intermediate concepts of Digital TASAR, 4D TASAR, and Strategic Airborne Trajectory Management and finally to fully autonomous choice of trajectory without ATC involvement (AFR). During this period of development, the drone community was making great strides in vehicle design and operating capability. Advanced Air Mobility (AAM) was gaining traction, and it was clear that VFR and IFR would not work for uncrewed, autonomous vehicles. This led NASA to move from a single-vehicle centric model to a multi-vehicle model called Digital Flight encompassing all airspace users and accommodating the breadth of the performance spectrum in both speed and altitude. The concept shifted from a set of rules for automated separation to a new flight mode, an alternative to VFR and IFR whose operations could seamlessly integrate with those legacy operations. The digital flight guidance could also be used directly by the aircraft autopilot and not require a human pilot to use it. One last name change, to Digitally Enabled Cooperative Operations, or DECO, highlighted the cooperative practices that define Digital Flight. DECO is not just CD&R, but an implementation of CD&R that optimizes all resolutions to encounters, cooperates with ATC, and separates appropriately from those under ATC control.

The final work on the concept focused on the means for FAA to approve the new operating mode. The NASA team proposed that FAA approval would come through the proper assignment of accountability for the safe use of Digital Flight in the airspace, and defining the necessary performance of the subsystems that create the trajectory guidance to achieve the necessary safety level when used in regular operations. When accountability [3] and performance [2] are correctly defined and assigned, even this revolutionary way of operating in the National Airspace System can be approved for use.

In conclusion, NASA took the gains from decades of previous research and created both a concept and design framework for operator-centric, automated conflict management. Digital Flight is an optional flight mode designed to be used by any flight operator (from drones to airliners) in all classes of airspace, in an integrated, non-interfering fashion. Using the technical elements of Information Services and Connectivity, Shared Traffic & Intent Awareness, Cooperative Practices, and Automated Conflict Management Capabilities to achieve the principal capabilities of Digital Flight, the new operating mode can be used while maintaining order in the airspace and allowing flight efficiency for all. All these capabilities have evolved from prior work done in this area and when implemented using the full list of cooperative practices, the goals of all the work over the past decades will have been achieved.

A Regulatory Perspective – *by Paul Vajda and Dr. John Maris*

A long-term Digital Flight implementation would consider rule-changes based on DFV and performance margins, particularly between cooperating Digital Flight aircraft. Figure 4 provides a generic decision tree for the exercise of Digital Flight functions for combinations of Digital Flight and Non-Digital Flight traffic interactions under VFR and IFR.

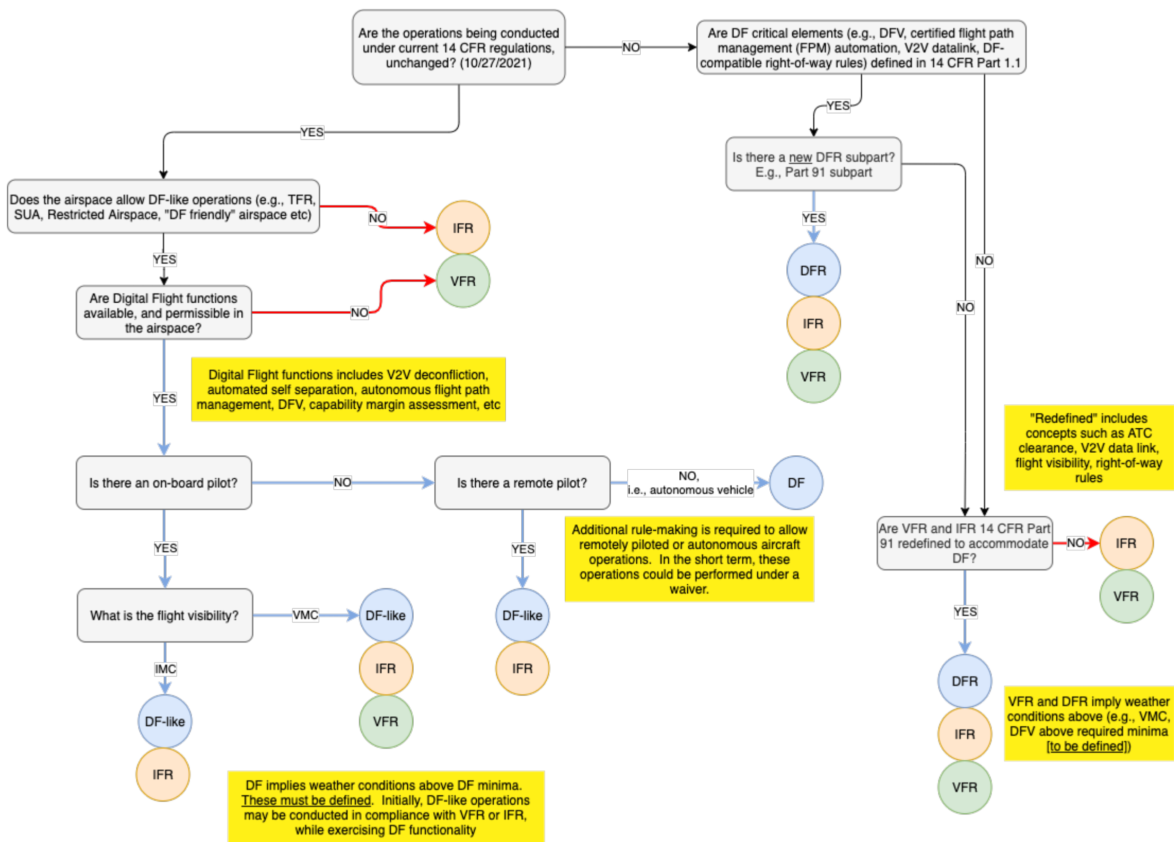

Figure 4: Digital Flight-like and Digital Flight (DF) availability in the NAS

As the figure illustrates, several "Digital Flight-Like" operations could be conducted *today* under VFR or IFR, subject to the appropriate traffic intent information being made available. Indeed, the TASAR, Traffic Aware Planner (TAP), and DECO2 flight trials (discussed below) have demonstrated this in practice.

Short term

Over the course of the research performed on Digital Flight, a regulatory gap analysis performed on Parts 91, 121 and 135 revealed most regulatory gaps of relevance to airspace operation are found in Part 91, and that most gaps are a result of Digital Flight not being envisaged in the original rule making process rather than being the result of direct prohibitions. Results of the gap analysis are found in Appendix D.

Notwithstanding regulatory gaps, the following steps would result in a limited near-term deployment of Digital Flight, based on the current regulatory environment:

1. Identify Digital Flight-friendly airspace and regulatory changes to support limited Digital Flight operations in such airspace. Examples are provided in Appendix E.
2. Commence regulatory definition updates (14 CFR 1.1) for concepts such as Digital Flight Visibility (DFV), Capability Margins and Available Power Profile. This is to allow for the regulatory development cycle in preparation for the widespread adoption of Digital Flight.
3. Update advisory materials such as AC 90-105 (Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System) [26] to encompass Digital Flight operations.
4. Ensure an on-going discussion regarding the evolution of ATC procedures to encompass Digital Flight operations.
5. Continue technical discussions for the certification of critical Digital Flight technologies (e.g., detect and avoid, non-deterministic systems, advanced automation, flight path management).
6. Ensure that ongoing development of Minimum Aviation System Performance Standards (MASPS) and MOPS for items such as data link systems are updated with Digital Flight operations as an integral component (e.g., ADS-B and C).
7. Implement working group(s) to develop and evolve:
    a. the current right-of-way rules which will enable advanced Digital Flight operations. This may include the rulemaking for DFV and aircraft capability margins.
    b. Flight path management.
    c. Digital Flight data requirements (such as that of ASTM WK73142 for Supplemental Data Service Provider (SDSP) weather data).
8. Map existing consensus standards to DFR requirements and identify any gaps.
9. Identify flight crew training requirements.

Medium term

This phase assumes a preliminary deployment of Digital Flight with a degree of stakeholder acceptance and adequate demonstrated Communications, Navigation and Surveillance (CNS) reliability, availability, and accuracy.

1. Development and initial deployment of ATC procedures for expanded Digital Flight operations (e.g., between cooperative aircraft in tightly defined airspace).
2. Trial implementation of new right-of-way rules between participating aircraft in Digital Flight friendly airspace.
3. Develop supporting Digital Flight regulations.
4. Allow revenue flights.

Long term

This phase assumes a successful intermediate deployment of Digital Flight with a high degree of stakeholder acceptance and robustly demonstrated CNS reliability, availability, and accuracy.

1. Finalize Digital Flight regulations as per the rule making process.
2. Unrestricted implementation of Digital Flight.

A Flight Test Perspective – *by Dr. John Maris*

An important aspect for the validation of the DECO concept was the live demonstration of some of its principal capabilities in the NAS. This was accomplished by two sets of flight trials [27] [28] using the TAP software installed in Advanced Aerospace Solutions, LLC ("AdvAero") Piaggio P180 test bed. TAP was a subset of the previously introduced AOP software, tailored for airborne use. The TAP trials were followed in 2025 by a demonstration of the DECO self-sequencing capabilities using a Pilatus PC-12 platform.

TAP Flight Trials

The TAP flight trials employed broadband datalink, ADS-B in, and aircraft data interfaces to continuously and unobtrusively offer route and altitude trajectory optimizations to minimize enroute time or fuel usage, as selected by the pilot. Of note, these optimizations automatically deconflicted the proposed trajectories from known (ADS-B) traffic, convective weather, and restricted airspace. The TAP output was continuously updated and unobtrusively displayed on an Electronic Flight Bag (EFB) device, without pilot intervention, until a trajectory change was accepted by the pilot. From an ATC perspective, TAP-inspired trajectory changes manifested as well-informed requests from the aircraft (which were almost always granted) thereby living up to the original project acronym "Traffic Aware Strategic Aircrew Requests" (TASAR). Remarkably, the TAP flight trials were conducted under IFR during peak traffic periods in the extremely dense eastern seaboard corridor, with no special handling provisions for the test aircraft: the Center controllers had no knowledge of the nature of the TAP flights, although the Center supervisors were extensively briefed and debriefed in order to obtain both sides of the evaluation. These IFR operations clearly validated the DECO *operator self-separation* principal capability at the strategic level.

The TAP flight trials were flown with senior personnel from various airlines, including Captain Bill Cotton – a co-author of this report – and the feedback was unanimously positive. ATC also reacted positively to the mission aircraft's behavior, which is perhaps unsurprising given that the test software reduced potential conflicts without any attendant increase in ATC workload or reduction in safety margins. These outcomes bode well for the continued development of the DECO concept towards full autonomy with intelligent self-separation, particularly between cooperating aircraft.

DECO2 Flight Trial

The 2025 DECO2 flight trials (Figure 5) primarily explored the DECO *pairwise coordinated separation* and *self-organization* capabilities [29]. The objective of the study was to demonstrate that two virtual aircraft and a "live" PC-12 NG aircraft operated by AdvAero could self-sequence their arrival at a designated feeder fix when initialized on intentionally conflicted flight paths.

Rule-based software developed and implemented by Mosaic ATM was used to resolve these conflicts. Virtual Flight Management Systems broadcast judicious speed changes to the aircraft using a GoGo broadband interface to achieve an orderly arrival at the designated feeder fix with a safe minimum along-track separation. Multiple flight patterns were flown, and a wealth of data was collected that showed that the Digital Flight self-organization capability was achievable in a real-world operational environment. Once again, the DECO functionality was transparent to ATC, even under IFR, with the exception that the computed speed changes were verbally requested by the pilot and approved by ATC.

Figure 5: From left, Andy Lacher (NASA), Kerry Doherty (AdvAero), John Maris (AdvAero Pilot-in-Command), Paul Vajda (AdvAero Second-in-Command), Fred Wieland (Mosaic ATM Principal Investigator), Matt Grochowalski (GE Aviation Systems), David Wing (NASA), and Puthy Soupin (AdvAero)

Engaging the Industry – *by Anna Dietrich*

The industry workshops conducted were an opportunity to explore in depth how key stakeholders and experts across the autonomous aviation ecosystem were thinking about the disconnect between emerging technology and existing regulatory frameworks and the role of both technology and flight rules to address it. Through a series of case studies and structured conversations, the distinction between a technology solution like detect and avoid, the practical limitations of the current flight rules (VFR & IFR) due to their assumptions about the role of an onboard pilot, and the way in which accountability is distributed were illuminated. Ultimately, these conversations were folded into a further refined version of DECO research and used to more clearly articulate the central issues associated with merely modifying IFR or VFR to accommodate autonomous aircraft from a practical perspective.

The question of accountability – for what and to whom – was a unifying thread throughout the workshopping and refinement of this work. When conceptualizing the regulatory framework that will facilitate a scalable digital and autonomous future for aviation operations, it became clear that simply defining technical metrics and flight rules, while necessary, was insufficient. A party cannot be accountable for an outcome that they have no influence over. That outcome must have quantifiable metrics specific to the technology being used that determine whether or not it is acceptable from a safety and efficiency perspective. The existing ambiguity that is acceptable today due to the ability of the system to work out an appropriate set of consequences and corrective actions based on history and long-held assumptions is no longer tenable. In order to properly oversee autonomous operations, the additional clarity that can be derived from this work is necessary.

Recent regulatory actions have highlighted the need for new frameworks within which to operate uncrewed and increasingly autonomous aircraft. Both 14 CFR 107 – Small Unmanned Aircraft Systems and the proposed Part 108 – Operations of Unmanned Aircraft Systems Beyond Visual Line of Sight and Part 146 – Automated Data Service Providers (Notice of Proposed Rulemaking issued August 2025) represent efforts to facilitate operations that are fundamentally different from the manned operations that underpin the assumption of 14 CFR 91 – General Operating and Flight Rules. Part 107 and Part 108 deal with the operations of the UAS themselves. Part 107 accommodates the unique practicalities of operating an uncrewed aircraft but still defines a remote pilot that is deemed qualified for their role by the FAA and does not fundamentally change the relevant accountability structure. This limitation is part of why Part 107 operations are limited to be conducted within the visual line of sight of the remote pilot – in other words within the range in which their ability to influence an outcome more closely aligns with their accountability for that outcome.

Both Part 107 and Part 108 are applicable in low altitude, effectively segregated airspace, but Part 108 operations are even further removed from the direct oversight and control of a pilot. Part 146 proposes requirements for a new type of entity in the operational ecosystem, further evolving and expanding the accountability landscape.

By creating operational permits and certificates with increasing levels of requirements and associated privileges while simultaneously removing FAA-imposed pilot requirements (in fact "pilots" are no longer referenced), Part 108 presents a new accountability model with the operator at its core. It is the operator as an entity that is responsible for ensuring that any involved operational personnel are appropriately qualified to perform their duties and that any aircraft flown are in an airworthy condition. Where Part 108 stops short is, however, with interoperability of UAS flown under this model with aircraft in the full NAS being operated under Part 91 with a pilot-forward accountability model. These two accountability constructs collide most notably with the issue of right of way, conflict management, and collision avoidance.

One of the tools that has been proposed to facilitate this interoperability, and thus full airspace integration, is the use of third-party data providers. Called automated data service providers (ADSP), these organizations are anticipated to support operations under Part 108 and beyond. By providing a pathway for ADSP to receive organizational certification, Part 146 creates an accountable entity in the form of the ADSP that can assume a key role in a future operational construct supporting integrated autonomous operations. Unfortunately, Part 146 as proposed stops short of explicitly enabling distributed digital deconfliction and conflict management which would build upon the accountable operator structure of Part 108: the ADSP is retained as a centralized entity rather than enabling aircraft to dynamically self-separate (strategic conflict management is included as a requirement). While both Part 108 and Part 146 are only in draft form at the time of this writing, the overall approach that they represent is encouraging and suggestive of additional work that could be done to further the integration of autonomous operations into the full NAS.

Building on the DECO work and associated workshop conversations, this future integrative work needs to address the accountability question in such a way as to align accountability and ability to influence outcome(s) and provide unambiguous requirements for the performance of accountable parties. This is not as straightforward as replacing references to human pilot tasks with autonomy-friendly terminology (e.g., replacing "see" with "detect" in 14 CFR 91.113(b)): while these practical revisions are likely necessary, making these changes without addressing the more foundational question of accountability may in fact be counterproductive to the broader, scalable integration of autonomous aviation.

Ideally, technical requirements development and existing rule language adaptations that support digital and autonomous operations would occur in step with more fundamental shifts in accountability.

7. PERSPECTIVES ON FUTURE CONCEPT REFINEMENT

As stated earlier, there is no playbook for developing an operating mode in the NAS. The DECO research activity in particular, sought to move the thinking on the future state of aviation from the aspirational visions of "Sky for All" [14] and "Charting Aviation's Future: Operations in an Info Centric National Airspace system" [10] to an implementation paradigm that can form the basis for a roadmap to achieve those visions. Concepts initiated in this process can form the basis for future research and development.

The digital operating mode concept is already seeing industry momentum as evidenced by numerous reports endorsing and building on the approach, these include:

- Digital Flight: A New Cooperative Operating Mode to Complement VFR and IFR - NASA Technical Reports Server (NTRS) downloaded more than 15,000 times from NTRS site.
- Industry calls for national priority investment in Digital Flight research.
- Sky for All and FAA materials including digitally enabled cooperative operations as a fundamental construct of emerging concepts.
- GAMA EPIC Committee recommendations for Digital Flight Operations in AAM midterm epoch. (Sep 2024)
- European ATM Master Plan inclusion of Digital Flight rules as a top 3 topic for fundamental research (2025 edition).
- SESAR 10M Euro solicitation for funded research on Digital Flight rules (2025).
- "DLR Blueprint: Initial ConOps of U-Space Flight Rules" citing Digital Flight rules. (May 2024)
- CATS Global Council Think Paper on Flight Rules citing Digital Flight rules in its call to action. (Jul 2025)

Using ETM to Mature Digital Flight – *Dr. Ruth Stilwell*

ETM can provide an opportunity to develop and mature digital conflict management technologies and procedures in the near term without requiring modification to NAS automation because of the distinct operating environment above Flight Level 600. This presents an extraordinary collaboration opportunity for both FAA and the High-Altitude operator community. While the Google Loon project relied on the absence of separation standards for unmanned free balloons, it provided a multi-year experience with a private sector operator managing flights in the upper Class E airspace without disrupting other NAS operations. Required descents into Class A airspace were managed through conspicuity and impacts on the system were limited and manageable over the multi-year activity. Using this airspace to collect operational data to validate similar use by fixed wing aircraft, demonstrating separation provision capability where interaction with manned aviation is naturally limited, can provide the necessary data to support the development of a routine digital operating mode in integrated airspace. The synergies with FAA initiatives detailed in Appendix C illustrate the converging thought leadership in upper Class E airspace and the benefits of connected aircraft envisioned by the Info-Centric NAS. Access to intent information opens the door to new paradigms for air traffic. Early access to upper Class E airspace using intra-operator shared intent (as illustrated by the Loon project) can provide valuable operational data while systems of inter-operator intent data sharing are developed and approved.

ATC as Cooperator

We should not be constrained by a one size fits all approach for information sharing tempo. Different aircraft characteristics in shared airspace can be managed by adjusting the time requirement for sharing information based on the needs of the conflicting traffic. Setting prescriptive requirements (e.g. 15- minute look ahead) may not reflect the needs of the airspace and other users. The example of a supersonic aircraft in conflict with a slow-moving High-Altitude Platform System (HAPS) is often raised as a high risk or unmanageable situation because of limited maneuverability of the supersonic and the slow airspeed of large solar HAPS. That view considers the tactical layer of conflict management but ignores the ability to manage conflicts strategically. The determining factor is time. How long in advance does the supersonic need to share intent if the HAPS will be required to maneuver away from the intended route? We may think of intent sharing in terms of minutes, but the physics of a given encounter may require us to think in terms of hours or days.

Who shares the intent information can also be defined based on the operational details of the flight profile. Air traffic controllers have always relied on access to intent information (flight plan) in managing traffic through a sector. A premise of Digital Flight is that it does not impose new requirements on IFR or VFR traffic. As such, we would not expect an IFR aircraft transiting upper Class E airspace to be required to participate in a cooperative information sharing structure. However, as ATC has the intent information on the aircraft, including position information, assuming the role of "cooperator" as the IFR transits a cooperative operating area resembles a point out. A point out is a routine ATC procedure to allow an aircraft to enter airspace under someone else's control without transferring communications or control.

The notional scenario of ATC as a cooperator is depicted in Figure 6. This scenario may be helpful to identify the types of information and interfaces needed for safe interaction between operating modes. In Figure 6, a Supersonic IFR flight is transiting a cooperative area. This scenario assumes that ATC could serve in the role of cooperator on behalf of the IFR aircraft. This model is not constrained to supersonic

Figure 6: ETM Scenario – ATC as cooperator for IFR flights

and could consider any IFR aircraft. We use supersonic because it requires the longest advance notice to aircraft within a cooperative area and can help illustrate the opportunities presented by shared intent to build integrated airspace approaches even when aircraft have dramatically different performance characteristics.

The scenario assumes an approach similar to an ATC point out procedure. Rather than coordinate with a controller in adjacent airspace, the controller shares intent information with the cooperative operators in the airspace. ATC has access to the intent information for aircraft operating within the cooperative area and aircraft operating in the cooperative area have information from the NAS regarding the IFR aircraft. In making the analogy to a point out, an IFR flight that conforms to its precoordinated intent volume would transit the cooperative area as if it were “point out approved”. An IFR flight that is outside the precoordinated intent volume is analogous to “subject (traffic), point out approved” and the controller takes appropriate action to resolve the traffic conflict. For the IFR aircraft, no action is required as ATC retains accountability for separation from other aircraft.

Validation of Required Conflict Management Performance Using Cooperative Areas

The existing ETM ConOps presents the concept of cooperative area within which “Industry-formulated vehicle separation measures (e.g., separation envelopes), approved by the FAA [9]” are anticipated. The ConOps further states, “non-prescriptive solutions can minimize deployment and development time by utilizing industry-provided technologies (e.g., mobile communications, existing ground and air infrastructures) capable of meeting appropriate performance requirements for safety, security, and efficiency [9].”

This process is predicated on the existence of performance requirements for safety, security, and efficiency. The work so far has focused on what a Digital Flight operation needs to do to integrate into the NAS, including the essential elements of Digital Flight and the development of candidate Cooperative Practices. In progressing this work, there is value in moving the discussion toward how well these elements need to perform in order to achieve certain goals. Describing the performance characteristics in terms of capacity and risk could serve to build community support and understanding. For integrated airspace the traditional safety mitigation techniques, like safety pilot or overlaying existing procedures, may be necessary. However, the concept of cooperative area presented for ETM creates a different opportunity.

Rather than assume a single standard for separation in a cooperative area, a construct of performance based cooperative areas allows more advanced operators to demonstrate and mature more sophisticated technologies and benefit from the investment without requiring other operators to meet the same performance standard before benefits can be realized. This approach is consistent with other airspace management techniques in the NAS, like RNP or RVSM, where capability is a determinant of access and airspace capacity. To progress this work, the team developed a notional case study.

Notional Case Study:

Cooperative Area A has a performance standard of CA34, allowing for operator-responsible separation standard of 34 miles (IFR/Domestic Procedural). This assumes the aircraft has an uncertainty similar to one based on pilot position updates, and route and time uncertainties are affected by winds and other elements. This allows for early access to the airspace relying predominantly on planned route deconfliction, requiring advance notice on intent changes that are essentially replanning and deconflicting route structures. The separation standard provides the safety mitigation for variability in performance.

Cooperative Area B has a performance standard of CA5, allowing for an operator-responsible separation standard of 5 miles (IFR/surveillance equivalent). This assumes the aircraft operates with a high degree of conformance to route and time parameters and is assured by a high update rate of confirming and shared information. Changes to intent can be made and accommodated with shorter notification requirements, allowing for a dynamic operating environment with high aircraft densities.

In order to operate in an area, technology independent performance standards are developed that describe:

- Participation in a shared situation awareness construct
- Update rate of shared position information
- Accuracy of position information
- Time requirement for notification of intent changes
- Route and time conformance standard
- Approved separation automation
- Performance values based on the desired demand density for the volume of airspace.

This approach assumes that you reach performance of X, you can use a separation of value Y. The advantage of this approach is that early cooperative areas can be established with relatively low performance requirements, allowing for experimentation, maturation, and validation of various technical solutions and evolve the separation to accommodate areas of higher demand without placing unnecessary mandates on operators seeking access to low demand airspace. This is consistent with historical evolution of airspace management approaches, albeit a more aggressive approach that provides a more apparent first mover advantage than earlier efforts. Industry feedback from our first workshop seemed to indicate that this approach was not necessary and may delay the process of integration. Rather than discard the option, the idea is provided as a potential path for regulators to build confidence in the certification and adoption process if needed.

Urban Arrival Concept – *by Paul Vajda and Dr. John Maris*

By shifting separation responsibility and navigational autonomy to the operator, Digital Flight enables novel airspace structure and management concepts. The following concept applies to the airspace directly overlying a vertiport, which hosts multiple arriving and departing eVTOL traffic. The airspace structure and procedures provide an example of how Digital Flight's strategic Principal Capabilities (PC) can be applied in tandem with the enabling concepts described previously. As a reminder, the PCs of interest are 4, 5 and 6 [14]:

PC4 – Constrained resource collaboration: The capability of operators to collaborate with arrival flow management by contributing dependable future states of their aircraft to enable more efficient use of capacity-limited airspace resources.

PC5 - Self-organization: The capability of operators to perform distributed local interactions that create order among aircraft to meet a shared operational objective, usually sequencing and spacing to land.

PC6 - Self-limiting density/complexity: The capability of operators in a distributed, automated fashion to apply appropriate mitigations, as traffic volume increases, to ensure safe operations are maintained at scale.

Urban Arrival/Departure Structure

The airspace centered on and above the vertiport is organized in circular rings in which the approaching aircraft can either "loiter" or "transition from a loiter" to a final approach path (Figure 7). The purpose of loiter rings is to allow for a constant flow of aircraft to approach the vertiport airspace and remain in consistent forward motion while the vehicles wait their turn to land. In a given ring configuration:

1. There can be several loiter rings stacked on top of each other with sufficient altitude buffer to guarantee vertical separation between vehicles. The number of rings changes with traffic volume.
2. Traffic flows clockwise

3. The lowest ring of the stack is a transition ring, where loitering is not permitted
4. The cylindrical airspace volume inside the rings remains clear of traffic.
5. Aircraft in loiter rings are “loitering” and aircraft in the transition ring are “transiting”.
6. As vehicles depart the vertiport making space for arrival traffic, aircraft in the lowest loiter ring to descend to the transition ring vacating their spot in the lowest loiter ring. This causes all other vehicles in the higher loiter rings to descend one ring in the stack.
7. After joining the transition ring, the vehicle transits along it to its designated point of entry into the final approach airspace volume. At that point, the vehicle is out of the ring system and is headed towards an already vacated pad.

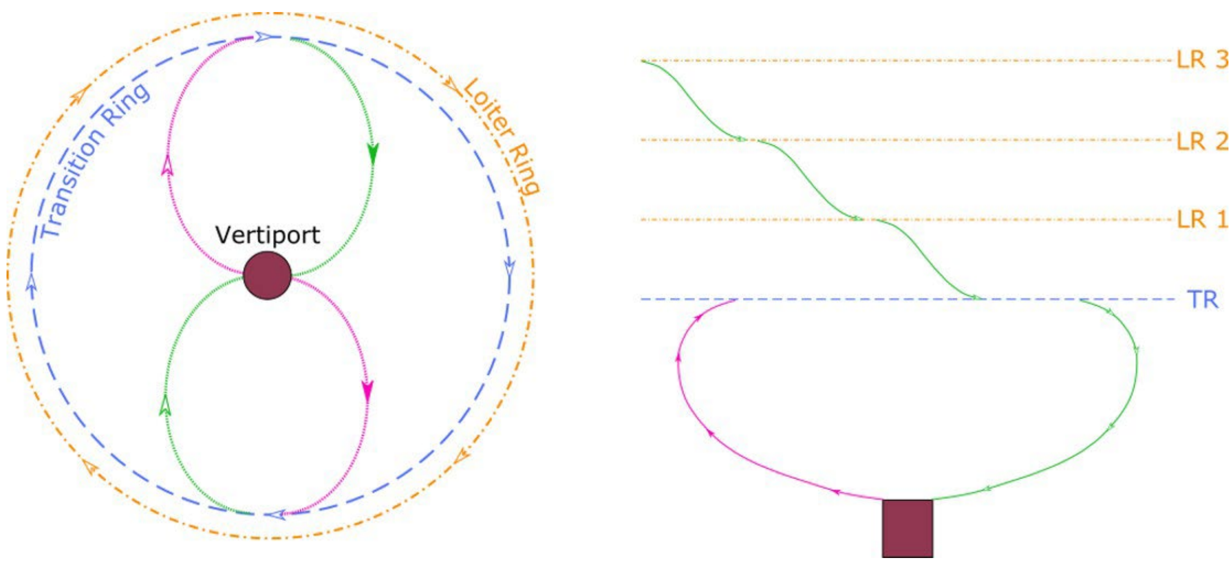

Figure 7: Airspace ring structure top view (left) and side view (right)

Urban Traffic Flow Management

Principle capabilities 4, 5 and 6 are applied for effective traffic flow management in the ring system. Right-of-way rules are applied to provide a governing framework for PC5. The right-of-way rule hierarchy is described from left to right in order of increasing priority:

Loiter Ring 3 < Loiter Ring 2 < Loiter Ring 1 < Transition Ring < Arrival traffic < Departing traffic To enter and navigate the airspace structure, an aircraft might follow the steps depicted in Table 3.

Table 3: Ring airspace structure procedures

Step	Action	Principal Capability
1	To enter the airspace, an arrival vehicle must become a member of a cooperative forum. To do so, it submits a status card to the managing agency for distribution to the other forum members which includes arrival time, energy reserves, maximum loiter time, and any other relevant state or intent data.	4
2	The managing agency provides the status cards of all other forum members to the arrival. The arrival analyzes the air traffic volume and determines if it is able to proceed normally.	4
3	If the arrival is not able to "wait its turn", it has the option of attempting to negotiate a swap directly with any other vehicle in the airspace structure.	4, 5
4	In the event that the arriving traffic increases the traffic density above what is permissible, the controlling agency automatically adds an additional loiter ring above the others	6
5	Once established in the loiter rings, aircraft communicate with each other to maintain adequate spacing	5
6	If the airspace must be closed, or the controlling agency experiences a failure, the airspace closes to arriving traffic. In this scenario, all aircraft within the cooperative forum already have each other's information and can continue to cooperate with each other. Departures and arrivals are able to continue, which slowly empties the rings.	5, 6
7	In the event an aircraft experiences an emergency, it descends through the core of the airspace by flying a shorter radius circle. In this case, it gains "emergency" membership and has priority landing rights (Figure 8).	4, 5

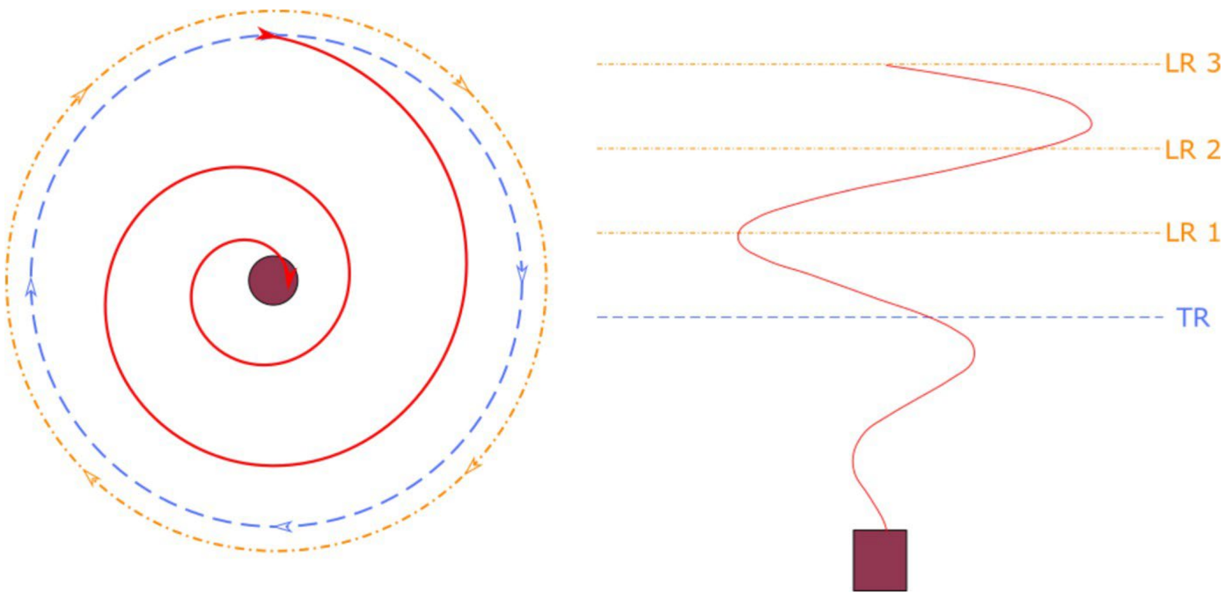

Figure 8: Emergency descent path through the core of the ring structure.

Digital Flight: Next Steps – *by Captain William Cotton*

NASA has published a full description of Digital Flight and descriptions of the accountability [3] and performance requirements [2] that would enable its approval in a new, alternative operating mode to VFR and IFR. The new operating mode is essential to the economics and safety of uncrewed flight operations and would improve both the efficiency and safety of legacy VFR and IFR operations. The next steps toward achieving the Digital Flight capabilities in NAS operations include the following:

FAA Acceptance of, and Support for the new Operating Mode

No matter how mature the systems are that provide operator-centric, automated conflict management, or how fervent the desire of operators to use them, nothing can happen until the FAA embraces the concept and approves the systems providing it, using agreed upon safety performance criteria. This means the automation systems must produce collision mitigation equal to or better than an accepted Target Level of Safety or equal to or better than an accepted safety performance level, such as that of the current IFR/VFR system.

Getting these policy decisions from the FAA will take concerted “whole of the aviation industry” support for the concept and strong advocacy by industry at all necessary levels of the FAA. The emerging DAA and UAS industry have the greatest, almost an existential, need for this to happen and so should lead the industry push to the FAA, but strong advocates from all other sectors must be sought out and recruited to the effort. The current administration has voiced support for “modernizing” the ATC system and a new digital operating mode can be included in what that modernization really entails, not just replacement of legacy equipment in the ground-based, IFR system.

Individuals in the industry who are Digital Flight proponents must work to coalesce an industry consensus to engage with the FAA in a strong and organized fashion.

Examination of Existing Systems for their Readiness to Fulfill the Essential Systems Functions in Digital Flight

Digital Flight, as proposed contains four Essential Elements for Digital Flight that are enabling technologies [1]. Another "next" step toward realizing Digital Flight is to examine existing systems for their ability to provide sufficient performance to fulfill the requirements of these essential elements. The first of these elements is digitally provided information on the weather and operational environment used in the separation management logic. Are there current standards in place that can be used to assess the performance of currently available sources of this information or do standards need to be created to be used by third party sources of this data?

The second Essential Element is Shared Traffic Intent and Awareness. How much of this can ADS-B IN and TCAS direct transponder interrogation provide? ADS-B IN provides identity, position and velocity vector but no further intent than that. Adding the identity and position from the transponder returns provides a redundant backup but adds nothing toward intent. While it appears that these may support DAA services, they do not offer the greater intent envisioned for cooperative practices among Digital Flights. What would need to be added to ADS-B IN or to a new ABS-B IN service tailored to the needs of Digital Flight, supporting all the described Principal Capabilities? These questions must be discussed in industry but may need to be resolved by FAA policy decisions.

The third Essential Element is the Cooperative Practices that ensure the automated conflict management will provide order in the airspace, when integrated with legacy operations, and complementary maneuvering among the aircraft using this new operating mode. A set of Cooperative Practices that are intended to achieve this goal have been created by the NASA team, but these should be scrutinized for their adequacy to the task. This scrutiny could be accomplished at the FAA or NASA.

The fourth and final Element is the automation system that uses information from the other elements to create a safe trajectory for the user to follow during the flight operation. This automation uses software that is designed to implement all the Cooperative Practices and achieve the Principal Capabilities in the provided trajectory. The trajectory provided by the automation is continuous during the flight operation and may be used directly by the autopilot to fly the aircraft or it may be used by a human pilot performing the same function. It is expected that avionics system suppliers will create this automation in accordance with established standards for performance, developed in the industry in bodies such as ASTM, RTCA, or SAE. Action will only come in response to demand expressed by the UAS community and other airspace users. The work of standards development can commence immediately as it takes time to complete, and the same industry advocates mentioned above can take the lead in calling for Special Committees to be established.

There are many parallels between the work that NASA has done on Digital Flight and existing projects within the FAA that provide some assurance that FAA may eventually support the idea of a new operating mode.

Among them are the FAA's ideas for Cooperative Operating Practices (COP) and user provided traffic management among aircraft operating in the Cooperative Areas (CAs) [10]. The RTCA committee on Digital Flight might have its terms of reference expanded to include developing MOPS for Cooperative Practices (CP) and Principal Capabilities (PC), beginning where NASA left off and describing the logic in sufficient detail so that companies can write software to implement them. The task of creating logic to automate the PCs and CPs is not at all simple as there are many ways to accomplish CD&R, beyond the simple logic of TCAS and DAA. To do it in a fashion that fulfills expectations for the NASA created PCs and CPs will be a major effort.

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The TAP and DECO2 flight trials have demonstrated that many of the Digital Flight Principal Capabilities can be implemented immediately, if suitable trajectory information is available, under VFR and even IFR operations, subject to trajectory change requests being approved by ATC. This is seen as a necessary stepping-stone to full implementation of the concept.

A three-phased regulatory approach is recommended to achieve a full implementor of Digital Flight. In the near term, a gap analysis should be performed to identify immediate Use cases for Digital Flight. In the interim, the Digital Flight-enabling technology will allow the concept to be deployed more fully, possibly in conjunction with enhanced right-of-way rules. Finally, the rulemaking process would result in a Digital Flight-enabled regulatory environment that would allow full advantage to be taken of the new Digital Flight operating mode to take its rightful place along alongside VFR and IFR for the benefit of all users of the NAS.

8. CONCLUSION

The aviation industry stands at the precipice of a transformative era, driven by the integration of digital systems and automation. The concept of Digital Flight, as explored in this report, represents a significant departure from reliance on solely human-centric procedures. The insights gathered from a diverse group of subject matter experts highlight the potential for operator-responsible separation based on digital information that can integrate with the existing routine IFR and VFR operating modes. The purpose of this research is not to provide an aspirational vision of the future, but rather a clearly articulated path forward to achieve a future state where digital, instrument, and visual flights operate in fully integrated airspace without the need for waivers or special authorizations.

This research was far reaching, extending from theory through flight test and included significant industry engagement along the way. This report is intended as a tool for future researchers to build on the perspectives provided and the challenges identified. There are no short cuts or easy answers, but there are clear opportunities that can enable a future where digital flight operations are not regarded as a novelty or marginal airspace user but rather are as ubiquitous and routine as instrument or visual operations. By deconstructing these status quo operating modes, we identify the elements necessary for a new routine operating mode and where the introduction of separation automation creates gaps in the accountability and certification structures that need to be resolved. The companion NASA reports on Accountability and Required Conflict Management Performance provide insight to address those elements.

In addition to a new operating mode, the research examined alternative approaches, recognizing that various other approaches are feasible but may introduce barriers to full integration into controlled airspace. Reflection on prior research activities and progress on integrating automated systems into the NAS provides important insights into future opportunities. We recognize that Digital Flight is not, and should not be, a "clean slate" approach, but rather builds on decades of work to leverage advancements in avionics, connectivity, and machine learning to do more than accommodate new entrants and instead unlock opportunities to improve safety, efficiency, and access across the aviation spectrum.

The SMEs engaged in this research activity analyzed the concept of a Digital Flight operating mode from distinctly different lenses and priorities. However, each concluded that the development of a new operating mode was the most appropriate and necessary path forward to incorporate aircraft without a human pilot onboard and to leverage the opportunities created by digitally enabled operations in the NAS to meet the mobility demands of the American public.

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ACRONYMS

AAM	Advanced Air Mobility		HAPS	High-Altitude Platform System
ABTM	Airborne Trajectory Management		ICAO	International Civil Aviation Organization
ACAS	Airborne Collision Avoidance System		ICN	Info-Centric NAS
ADS-B	Automatic Dependent Surveillance–Broadcast		IFR	Instrument Flight Rules
ADSP	Automated Data Service Providers		LAANC	Low Altitude Authorization and Notification Capability
AFR	Autonomous Flight Rules		MAP	Missed Approach Procedure
AIP	Aeronautical Information Publication		MOPS	Minimum Operational Performance Standard
ANB	Air Navigation Bureau		NAS	National Airspace System
ANP	Actual Navigation Performance		NAT	North Atlantic
ANSP	Air Navigation Service Provider		NPRM	Notice of Proposed Rulemaking
AOP	Autonomous Operations Planner		PBCS	Performance Based Communication and Surveillance
APAC	Asia and Pacific		PBN	Performance Based Navigation
APP	Available Power Profile		PC	(DECO) Principal Capabilities
ATC	Air Traffic Control		PIC	Pilot in Command
ATM	Air Traffic Management		PinS	Point in Space
ATS	Air Traffic Service		RCMP	Required Conflict Management Performance
CA	Cooperative Areas		RNP	Required Navigation Performance
CD&R	Conflict Detection and Resolution		RPAS	Remotely Piloted Aircraft Systems
CNS	Communication, Navigation, and Surveillance		RVSM	Reduced Vertical Separation Minima
COP	Cooperative Operating Practices		SARP	Standards and Recommended Practices
CPA	Closest Point of Approach		SUA	Special Use Airspace
DAA	Detect and Avoid		sUAS	Small Unmanned Aircraft System
DAIDALUS	Detect and Avoid Alerting Logic for Unmanned Systems		TAP	Traffic Aware Planner (software)
DECO	Digitally Enabled Cooperative Operations		TASAR	Traffic Aware Strategic Aircrew Requests
DF	Digital Flight		TBO	Trajectory Based Operations
DFR	Digital Flight Rules		TCAS	Traffic Alert & Collision Avoidance System
DFV	Digital Flight Visibility		TBO	Trajectory Based Operations
EFR	Electronic Flight Rules		TLS	Target Level of Safety
EROS	Eliminate Range Zero System		UAS	Unmanned Aircraft Systems
ETM	Upper Class E Traffic Management		UCE	Upper Class E (airspace)
FAA	Federal Aviation Administration		UTM	UAS Traffic Management
FAF	Final Approach Fix		VFR	Visual Flight Rules
GATMOC	Global Air Traffic Management Operational Concept			

APPENDIX A: CONFLICT MANAGEMENT

Conflict management is the foundational construct in air navigation that limits the risk of collision between aircraft and hazards, including other aircraft. How conflict management is conducted, and which parties are accountable for the execution of conflict management, is defined by the operating mode. The ICAO Global Air Traffic Management Operational Concept (GATMOC) defines conflict management in terms of three layers, strategic conflict management, separation provision, and collision avoidance and offers definitions for these relevant terms in Table 4 [4]:

Reference Terms

CONFLICT - any situation involving aircraft and hazards in which the applicable separation minima may be compromised. (GATMOC 2.7.2)

CONFLICT HORIZON - the extent to which hazards along the future trajectory of an aircraft are considered for separation provision. (GATMOC 2.7.3)

HAZARD (that an aircraft will be separated from) **-** other aircraft, terrain, weather, wake turbulence, incompatible airspace activity and, when an aircraft is on the ground, surface vehicles and other obstructions on the apron and maneuvering area. (GATMOC 2.7.4)

SEPARATION MINIMA - the minimum displacements between an aircraft and a hazard that maintain the risk of collision at an acceptable level of safety. (GATMOC 2.7.5)

Note: The ICAO use of the term separation minima is a broader term than separation standard in common use, particularly in the U.S. where the term separation is used to refer to the application of a prescribed separation standard by an air traffic controller to IFR air traffic. The GATMOC uses the term separation more broadly to encompass separation provision from ATC, self-separation, distributed, and delegated separation.

SEPARATION MODE - an approved set of rules, procedures and conditions of application associated with separation minima. (GATMOC 2.7.6)

SEPARATION PROVISION - the tactical process of keeping aircraft away from hazards by at least the appropriate separation minima. (GATMOC 2.7.7)

SEPARATOR - the agent responsible for separation provision for a conflict and can be either the airspace user or a separation provision service provider. (GATMOC 2.7.18) The separator must be defined (that is predetermined) prior to the commencement of separation provision; however, the role of separator may be delegated. (GATMOC 2.7.19)

Table 4: Conflict Management Layers

CONFLICT MANAGEMENT LAYERS	
strategic conflict management	first layer of conflict management and is achieved through the airspace organization and management, demand and capacity balancing and traffic synchronization components. (GATMOC 2.7.10)
separation provision	second layer of conflict management and is the tactical process of keeping aircraft away from hazards by at least the appropriate separation minima. (GATMOC 2.7.13)
collision avoidance	not part of separation provision, and collision avoidance systems are not included in determining the calculated level of safety required for separation provision. Collision avoidance systems will, however, be considered as part of ATM safety management. The collision avoidance functions and the applicable separation mode, although independent, must be compatible. (GATM)C 2.7.31

APPENDIX B: SEPARATION SERVICES BY AIRSPACE CLASS

Table 5: ICAO Airspace Classification

Class	*Type of Flight*	*Separation Provided by ATC*	*Service Provided*	*Speed Limitation*	*Radio Communication Requirement*
A	IFR Only	All aircraft	Air traffic control service	Not Applicable	Continuous two-way
B	IFR	All aircraft	Air traffic control service	Not Applicable	Continuous two-way
	VFR	All aircraft	Air traffic control service	Not Applicable	Continuous two-way
C	IFR	IFR from IFR IFR from VFR	Air traffic control service	Not Applicable	Continuous two-way
	VFR	VFR from IFR	1) Air traffic control service for separation from IFR. 2) VFR/VFR traffic information (and traffic avoidance advice on request)	250 kt IAS below 3050 m (10 000 ft) AMSL (Above Mean Sea Level)	Continuous two-way
D	IFR	IFR from IFR	Air traffic control service, traffic information about VFR flights (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way
	VFR	Nil	IFR/VFR and VFR/VFR traffic information (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way
E	IFR	IFR from IFR	Air traffic control service and, as far as practical, traffic information about VFR flights	250 kt IAS below 3050 m (10 000 ft) AMSL	Continuous two-way
	VFR	Nil	Traffic information as far as practical	250 kt IAS below 3050 m (10 000 ft) AMSL	No
F	IFR	IFR from IFR as far as practical	Air traffic advisory service; flight information service	250 kt IAS below 3050 m (10 000 ft) AMSL	Continuous two-way
	VFR	Nil	Flight information service	250 kt IAS below 3050 m (10 000 ft) AMSL	No
G	IFR	Nil	Flight information service	250 kt IAS below 3050 m (10 000 ft) AMSL	Continuous two-way
	VFR	Nil	Flight information service	250 kt IAS below 3050 m (10 000 ft) AMSL	No
***When the height of the transition altitude is lower than 3 050 m (10 000 ft) AMSL, FL 100 should be used in lieu of 10 000 ft**					

APPENDIX C: SYNERGY WITH FAA INITIATIVES

The team considered existing FAA initiatives and determined that the option of a new digital operating mode was consistent with other forward looking FAA concepts. This was an important step in evaluating the feasibility of the DECO concept as a path forward for aviation's increasingly digital future.

Applicability to Info-centric NAS Concept of Operation

A comparison of the concepts of a digital operating mode and the FAA vision for an Info-Centric NAS at its highest level considers the motivation for each. The problem to be solved is not limited to the accommodation of vehicles without a pilot on board but also includes the benefits of increased connectivity that is being seen across the transportation sector. The vision for connected aircraft enables the sharing of intent information, a core capability for digitally enabled cooperative operations. In *Charting Aviation's Future: Operations in an Info-centric National Airspace System* [10], the FAA concludes:

> "…increases in telecommunications, computational power, storage, and new technologies help us secure, leverage, and learn from accumulated data. Rapid growth has resulted in these technologies reaching a level of maturity that allows for their use in safety-centric industries, such as air traffic management (ATM) [10]"

The ICN vision recognizes that the opportunities for a digital future for aviation are not limited to new entrants. ICN plays a critical role in continuing progress from NextGen and expands the vision for Trajectory Based Operations (TBO) by embracing performance-based technology alternatives, including the exchange of future trajectory information by connected aircraft. This foundational concept of digitally shared intent with the ATC system and other operators unlocks the potential to improve system performance and enable new concepts for operations in shared airspace. For operator-responsible separation decisions, sharing intent provides greater information than the foundational concept of see and avoid, creating the opportunity for a stronger safety paradigm than visual flight rules.

The digital operating mode embraces the aspiration of the Info-Centric NAS vision and provides specificity in how the benefit of increased connectivity is translated into operational benefits. Foundationally, the DECO team recognizes that aviation is on the threshold of tremendous change, but progress is constrained by the limitations of the current operating modes. In a technical memo on Digital Flight, [1] capabilities are described as not limited to the current information threshold but seeks to take full value of the benefits of an info-centric future state. In the document, Digital Flight is defined as:

> "an operating mode in which flight operations are conducted by reference to digital information, with the operator ensuring flight-path safety through cooperative practices and self-separation enabled by connected digital technologies and automated information exchange [1]."

A direct comparison of the documents describing Digital Flight and Info-Centric NAS reinforces common motivation and the need for change to meet the demands of the aviation sector in the 21st century (Table 6).

Table 6: Comparison of Motivation for Digital Flight and Info-Centric NAS

	Digital Flight [1]	Info Centric NAS [13]
Scalability	Need to accommodate higher densities and operational tempos than existing system	"current service accommodation will not scale to meet the expected growth in these operations"
Procedural Compatibility with self-piloted aircraft	Need to allow aircraft without a pilot on board to operate safely in shared airspace	"new operations must be handled using a new mode in which each new operation does not impose additional demands on the current ATS system and reduce its operational efficiency"
Operational Predictability	Recognizes standards are needed for sharing intent and conformance monitoring	"Quality of information, including uncertainty, will be incorporated into predictive models, allowing performance outcomes to manage the effect of uncertainty and improved predictability"
Operational Flexibility	Need for emerging new aircraft to operate at scale in varying wx conditions in multiple airspace classes	"vision is a more adaptable future where different types of operations are more flexibly authorized across airspace classes"
Regional Growth	Need to allow growth of runway independent operations and at non-towered airport	"technologies are also key in ensuring that the growth in the number and types of aerial vehicles can occur without disrupting traditional ATS"

ETM in the Info-Centric NAS Vision

While ICN proposes a NAS wide vision, Upper Class E (UCE) airspace creates specific opportunities to advance the concepts contained in the vision, and industry interest in the unique operating environment creates a sense of urgency. According to ICN:

> "The FAA's current Air Traffic Management (ATM) system cannot cost-effectively scale to meet the needs of this envisioned Upper Class E Airspace environment. The increase in operations, disparate vehicle performance characteristics, and unconventional operational needs require innovative solutions through public-private partnerships and leveraging other cooperative traffic management approaches, such as UAS Traffic Management (UTM) [11]."

The ETM vision to manage flights above 60,000 ft creates a cooperative traffic management environment where operators are responsible for coordinating with one another rather than relying on ATC for separation services (Fig. 9). The proposed ETM approach requires a separate set of procedures and standards for aircraft transitioning in and out of cooperative airspace volumes. In contrast, DECO creates a single uninterrupted operating mode throughout the flight, applying cooperative procedures across all of UCE, minimizing the demands placed on the air traffic system, and providing flexibility for operators throughout UCE.

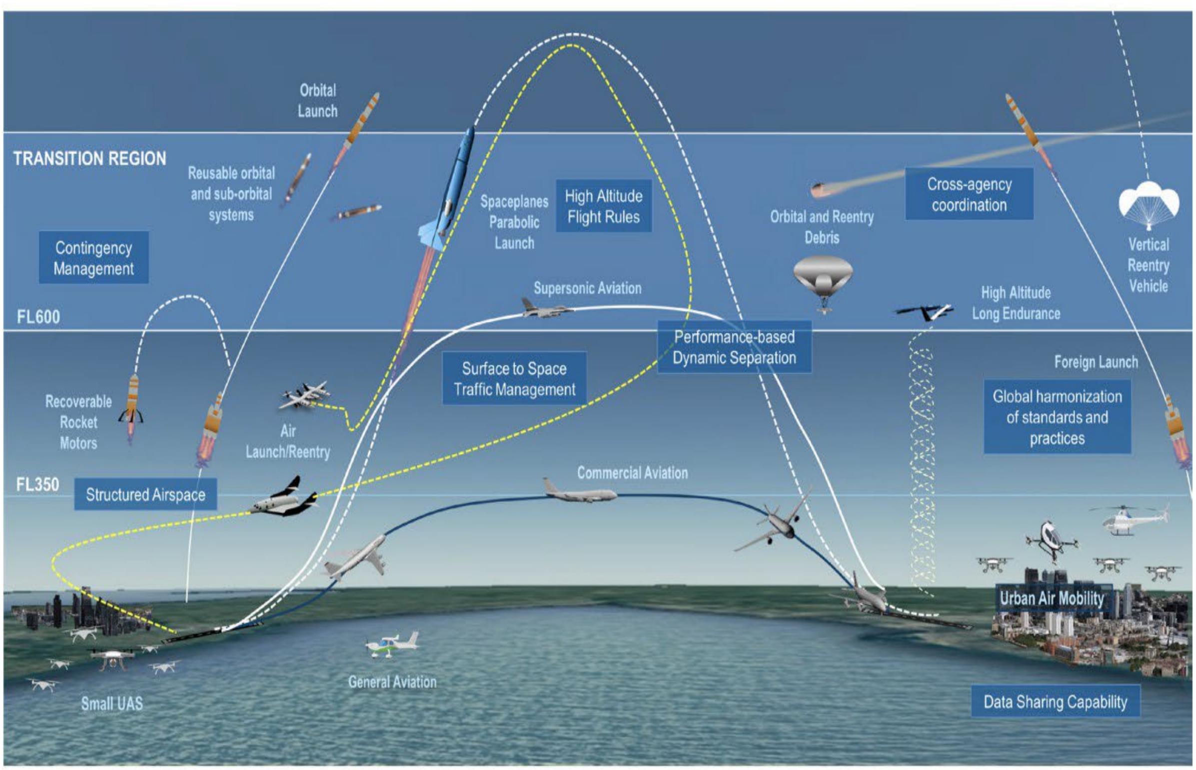

Figure 9: Vision of complex operations in upper class E airspace (Source: FAA: Charting Aviation's Future)

The ETM Concept was developed before the adoption of ICAO Annex 6, Part IV, providing the Standards and Recommended Practices (SARPs) to enable IFR flight by RPAS. The high-altitude operator community has consistently asserted that they are willing to conform to these standards in transit to and from UCE, but upon reaching their operating altitude, existing operating rules are inconsistent with long endurance, highly automated mission profiles.

Applicability to Upper Class E Traffic Management (ETM)

Similar to the ICN, there are considerable parallels between DECO and the ETM con ops as illustrated in Table 7.

Table 7: Common elements between ETM and DECO

ETM ConOps: Cooperative Separation		Common Element	Digitally enabled cooperative operations	
Intent Information	Spatial and temporal elements of a planned operation Enables operators to gain situation awareness of proximate operations	Shared intent as a central element	Shared Separation	Enables DECO operators to coordinate with each other to equitably and safely share or distribute the separation burden
	Supports demand/capacity balancing, deconfliction, advisories, and flight operations data	Info-centric, enabled by shared information	Self-Limiting Density/ Complexity	Enables DECO operators to sustain safe operations while scaling to increasingly complex environments
Flight Information Updates	Supports real-time separation management	Operator is responsible separator Not reliant on human onboard	Operator Self Separation	Enables DECO operators to provide their own separation from VFR, IFR, and other DECO aircraft in lieu of visual procedures and ATC separation services
	Comprised of active flight data, vehicle tracking, conformance, position, and V2V data	Highly automated separation	Pairwise Coordinated Separation	Enables DECO operators to tailor the separation criteria to each encounter
Airspace Constraint Information	FAA makes NAS airspace constraint data (i.e. SUA) available to cooperative operators	Minimal demand on ATC resources	Collaborative Utilization of Constrained Resources	Enables DECO operators to collaborate with ATC in arrival traffic synchronization and demand-capacity balancing

APPENDIX D: PART 91 REGULATORY GAP ANALYSIS SUMMARY

Existing Part 91 regulations clearly address VFR and IFR operations. Though some regulations explicitly conflict with some of the Digital Flight authorities, most regulations do not apply to (and did not envisage) Digital Flight; others do not address critical Digital Flight elements, such as the use of datalink for Vehicle to Vehicle (V2V) communications or DFV. The establishment of new flight rules would be consistent with establishing a new automated separation mode, while minimizing the changes required to current regulations. Digital Flight may be implemented through new rulemaking and via selected rule amendments. Key rulemaking aspects and gaps pertaining to Digital Flight implementation are summarized below:

1. Most substantial gaps, barriers, and opportunities related to Digital Flight are located in 14 CFR Part 91, General Operating and Flight Rules.
2. Few regulations need to be amended to enable access to airspace classes without a specific clearance. However, for operations in Class E, C and D, a scalable process to authorize deviations from the rules for Digital Flight operators is required.
3. Deviations from controlled Class C, D and E could potentially disrupt current operations. New terminal procedures to ensure interoperability are required and should be reflected in JO 7110.65, including updates to terminology and phraseology.
4. Language in the regulations implies Class C, D, E, and G airspace may be more amenable to early Digital Flight operations.
5. Operations at uncontrolled G and E airfields are attainable in the short term because of the lack of communication requirements.
6. No regulatory changes are required to perform Digital Flight trials under VFR in G airspace, and in Class E airspace below FL180 and above FL600 (upper Class E).
7. Rulemaking to formalize the ATC facility approval mechanism under which Digital Flight traffic may deviate from 14 CFR 91.127, 129 and 130 (towered terminal environments).
8. Rulemaking will be required to define new right-of-way and traffic deconfliction procedures for encounters among Digital Flight aircraft. These new procedures may need tailoring to the class of airspace in which they are applied to ensure ATC compatibility.
9. 14 CFR 91.123 “Compliance with ATC clearances and instructions” must be amended to permit Digital Flight operations in controlled airspace. Alternatively, a Digital Flight “regulatory clearance” with non-prescriptive routing may be defined under which an operator navigates freely. Special VFR (SVFR) sets a limited precedent.
10. Digital Flight procedures will likely require new training requirements. An update to 14 CFR Part 61 would be required, but the requirements were not assessed in this analysis.
11. Operational benefits of RNP 0.3 outlined in AC90-105A make it a good initial candidate for trajectory conformance in the terminal area. Trialing Digital Flight operations at the RNP 0.3 level will help identify the required automation functions and data to support a digital operating mode, with later expansion to tighter performance. Benefits include:
    a. Reduced protected areas, enabling simultaneous nixed-wing and rotorcraft operations in dense terminal airspace
    b. Low level routes in obstacle rich environments reducing exposure to icing environments.
    c. Seamless transition from en route to terminal route
    d. More efficient terminal routing in an obstacle rich or noise sensitive terminal environment, specifically in consideration of helicopter air ambulance (HAA) IFR operations between hospitals
    e. Transitions to rotorcraft point in space (PinS) approaches (prior to the final approach nix (FAF) and after the Missed Approach Procedure (MAP))

12. There are no Part 91, 121, or 135 regulations that pertain to broadcasting or receiving flight path intent data, as will be required by Digital Flight. The consequences and severity of this gap are unclear at present.
13. Regulations seldom address coordinated and cooperative operations. Instead, guidance is found in the AIM and pilot handbooks. A formalization of digitally enabled cooperative operations will be required, particularly for areas of high traffic density.
14. The Digital Flight Visibility, Capability Margin and Available Power Profile concepts will contribute to performance-based regulations and standards required for Digital Flight. Developments on these concepts should continue.
15. There are three Digital Flight Trial -friendly airspace strata in the NAS, including the terminal Mode-C veil and ADS-B mandated airspace where all traffic will be known to the Digital Flight aircraft. Early DECO operations are likeliest to take place in remote locations in uncontrolled airspace, or between 10,000 feet MSL and FL 180.
16. Initial DECO operations may be conducted at FL390 and above to demonstrate the feasibility of autonomous trajectory management in sparsely occupied airspace.
17. Separation standards for Digital Flight's unique separation mode will need to be defined. In support of these standards, ATC will need high-quality intent data from DECO aircraft and will likely require tailoring of existing minimum separations as a function of the current Digital Flight maturity levels. In addition, for interoperability with VFR and IFR traffic, DECO aircraft will require a knowledge base of minimum traffic separation standards, including nuances such as wake turbulence, RVSM, RNP, and in-trail traffic spacing.
18. The Digital Flight automation will require data that may not be readily available in digital form today.
19. Amend Part 91, Subpart B to include a Digital Flight section alongside VFR and IFR, to include rules on:
    a. data requirements
    b. intent sharing
    c. communications
    d. airspace procedures to ensure interoperability with IFR and VFR traffic
    e. V2V deconfliction procedures
    f. procedures for obtaining an ATC clearance when necessary
    g. procedures for reversion to IFR/VFR in the event of equipment failures
    h. division of labor between automation and the crew or operator of uncrewed aircraft
20. Amend Part 91, Subpart C: Equipment to include Digital Flight equipment requirements.

APPENDIX E: DIGITAL FLIGHT TRIAL FRIENDLY AIRSPACE

The current airspace structure provides opportunities to test, in limited conditions, Digital Flight aligned procedures. Three airspace strata have been identified as candidate areas for testing and early implementation of Digital Flight procedures: urban areas, ADS-B airspace between 10,000 ft MSL and FL 180, and FAA's Non Restrictive Routing airspace at and above FL 390.

Urban areas

Accessible airspace in urban areas is defined between 400 ft Above Ground Level (AGL) and 1000 ft AGL. 14 CFR §107.51 specifies that sUAS must be operated below 400 ft AGL; §91.119 requires that, in congested areas, fixed wing aircraft remain 1000 ft above the highest obstacles; and §77.9 requires that any obstacle that is taller than 200 ft AGL be declared. These rules leave open a 600 ft deep slice of airspace that becomes accessible if relief from 14 CFR 91.119 can be obtained (Figure 10).

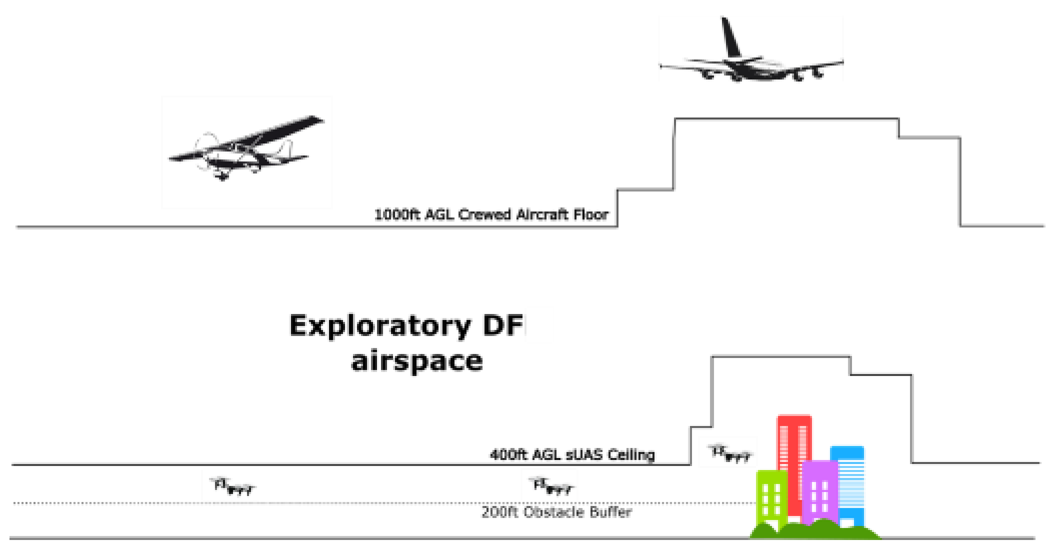

Figure 10: Urban Digital Flight airspace

Enroute airspace – 10,000 MSL to FL 180

In the enroute environment, airspace between 10,000 feet Mean Sea Level (MSL) and FL180 is available for exploration of Digital Flight-aligned operations (Figure 11). 14 CFR 91.225 mandates ADS-B above 10000 feet MSL, and 14 CFR 91.135 requires an IFR flight plan above FL180. This airspace is not constrained by the IFR requirement and has the added benefit of guaranteeing ADS-B data availability from all present traffic. Oxygen requirements are overlaid as an additional organizing factor. To access this airspace, aircraft could be issued an IFR clearance to a specific point in space and time analogous to a "VFR on top" clearance, or depart VFR if weather permits it.

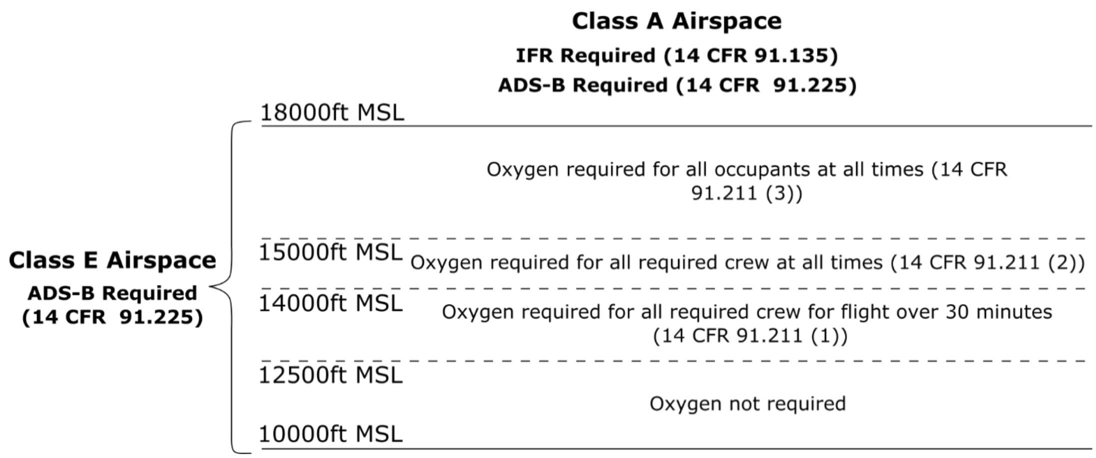

Figure 11: En route Digital Flight airspace

Enroute airspace – FL390 and above

Lastly, airspace above FL 390 utilizes the FAA's Non Restrictive Routing (NRR) initiative which provides a grid of waypoints available for navigation (Figure 12). Because airspace above FL 390 is sparsely occupied and is generally above the weather, the airspace layer extending upwards from FL 390 may prove to be fertile testing grounds for exploration of Digital Flight procedures. Relief from the Class A IFR requirement must be obtained, or an IFR clearance with non-specific routing could be issued.

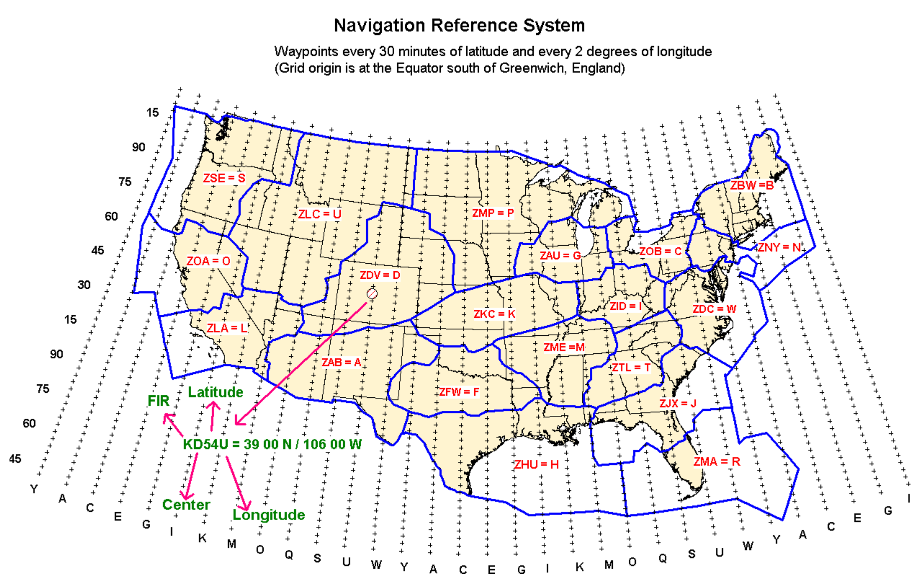

Figure 12: Non-Restrictive Routing waypoint grid